DESIGN OF A RANGE FOR PLOTTING PATTERNS OF SHIPBOARD ANTENNAS

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THESIS

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ABSTRACT

The need for a range to measure the effectiveness of ships' radiating systems is described. A three-step long-range plan is presented for the establishment of such a range. Special consideration is given to minimum cost, particularly in the initial phase. A design is given for this phase in which the key units are presented in detail. Readily available commercial or standard navy units are specified wherever possible. Options are presented and suggestions for future extension of range capability are included.

TABLE OF CONTENTS

ACKNOWLEDGEMENT

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I. INTRODUCTION

A. NECESSITY OF AN ANTENNA RANGE FOR NAVAL VESSELS

Shipboard antennas are affected by the vessel's superstructure in a very complex manner. There are, however, two major effects which can be readily identified if not completely analyzed. One is the impact on the radiation pattern of the antenna caused by the multiple reflections from adjacent structures. The second is the change in driving point impedance produced by the coupling between the antenna and the currents set up in the same structures. The purpose of an antenna is basically to produce some desired level of field intensity in a certain direction or directions. It is necessary, therefore, to know the radiation pattern of the antenna in the ship's environment in order to understand its performance. The character of the radiation pattern can affect the operational performance of the entire system. For example, a notch, in an omnidirectional pattern, caused by reflection from shipboard structures, can completely eliminate communication in a specific direction, or high sidelobe levels in a radar antenna pattern can cause false detections. It is important, therefore, that the operators be aware of any deficiencies in the radiation patterns in order that appropriate allowances may be made or corrective measures taken. The patterns of shipboard antennas can be measured with an appropriate range periodically or after any modification in the antenna or vessel structure, [Ref.1].

In order to obtain these patterns, it is necessary for the ship to operate in a circular track at some reasonable distance from the range

instrumentation. At the same time it is possible to obtain additional information on the performance of the ship's radiation systems. This might include absolute field strength levels, antenna efficiency and spectral information. It is the goal of this study to examine the various techniques which might be employed in the design of an antenna range. An engineering design will be proposed which will consider cost, manpower requirements, equipment complexity, time spent in measurement and the characteristics of the systems aboard ships.

B. PURPOSES OF AN ANTENNA RANGE

The major purposes of this antenna range are as follows:

1. On ships of new design or after major repairs or maintenance, determination must be made of the effects caused by any change in antenna characteristics on the operational capabilities. Also, limitations of shipboard electronic systems caused by changes in antenna characteristics can be found. This applies to communication systems, detecting and tracking radars, underwater detection systems, etc.

2. Information must be furnished to operational personnel which assists them in optimum employment of their antennas. By this means, tables can be derived from antenna patterns which show the most favorable antenna for specific communication tasks defined by frequency, ship course, location and propagation conditions.

3. Using this range, antennas on ships of new design can be completely evaluated.

4. Electromagnetic compatibility measurement around the ship and

inside of the ship can be made.

Totally, the range measurements will give quantitative information about the effects of antennas on the performance of related electronic systems. This information will be provided in appropriate reports. These reports will be given to operational personnel of the vessel to assist in optimum usage of the equipment, to the shipyard authorities to assist in effective maintenance and repair, and to higher authorities to inform them of the combat readiness status of the antennas, [Ref. 2].

C. PLANNING OF THE OBJECTIVES

The study of the range is initiated by identifying the specific objectives which would affect the engineering design of the range. Priorities are then assigned.

At the beginning of the study a plan is made to achieve these stated purposes for engineering design of the range, keeping in mind the consideration of costs and future expansion of the range. Priorities of objectives are investigated.

The objectives of the system are described in three phases. The first phase will include the systems which will be designed for most immediate requirements. The second phase will include only theoretical studies, and the last will consist only of statements of the objectives.

1. Phase I

a. Investigation of Site Environment

This study is necessary in order to find the environmental effects on the accuracy of the measurements and must include as well

consideration of necessary ship maneuvering area and noise levels within the range, [Refs. 3, 4].

b. Required Equipment

It is important that the initial installation at this range provide maximum information at minimum cost. Since the main body of information can be extracted from radiation patterns, the first objective will be to obtain antenna patterns, i.e., the field intensity or power density as a function of heading in a horizontal plane. This will require:

Equipment for telemetering ship-heading information for plotting at the shore station.

Meters for measurement of field intensity at the shore facility in order to obtain polar plots of communication antennas.

Meters for measurement of power output of ship radar antennas as a function both of antenna direction and of ship heading.

Meters for measurement of received signal in the front end of shipboard receivers independent of receiver gain.

Metering system for measuring boresight errors of fire control radars.

Polar and rectangular recorders.

The equipment listed above will make it possible to obtain sufficient information for evaluation of shipboard antenna systems with minimal cost in manpower, budget and site construction time.

2. Phase II

This part of the thesis will include theoretical studies which will be useful to consider in Phase I for future expansions of the range. The following is an outline of the objectives for this phase.

a. Field Intensity Patterns in the vertical plane

(1) Investigation of methods for vertical antenna pattern

measurements.

(2) Telemetering of analog information from an elevated position to the recording facility.

(3) Investigation of the positioning of elevated measurement antennas which are used for vertical measurements and means for storing this information.

b. Radio Direction Finder Calibrations

(1) Transmitting source at facility.

(2) Provisions to obtain visual information from transmitting source.

3. Phase III

Up to this point measurement of radar and communication systems are emphasized as first priority. Secondary objectives as stated below for ECM, IFF, and Underwater Detection Systems are placed in this deferred category because these systems are less widely used and the objectives can be achieved only at high cost.

a. Detection and Tracking Systems

(1) Investigations of power spectrum of radars and other performance checks on equipment.

(2) Range calibration of tracking radars.

b. IFF Systems

(1) Omnidirectional and directional antenna checks of IFF systems.

(2) Performance evaluation of IFF equipment.

c. Electronic Countermeasures Equipment

(1) Generation of specific signals within the limitations of shipboard passive ECM equipment for evaluation of performance and effective range of this equipment.

(2) Calibration of ECM direction finding equipment.

d. Underwater Detection Systems

(1) Source level, receiving sensitivity, receiving beam patterns and self noise measurements of active sonar systems.

(2) Performance measurements of passive sonars.

II PHASE ONE

A. SELECTION OF AN AREA FOR AN ANTENNA RANGE

1. Antenna Range Environment

The main environmental factors for antenna measurements are:

a. Reflection sources: buildings, characteristics of ground, trees, area geography of selected site, and power lines.

b. Noise sources: ambient noise level in the vicinity of the range, adjacent industrial areas, population, power lines.

c. Factors affecting ship maneuverability.

Reflection Sources. The major factor in the accuracy of the field strength measurement is the impact of the reflected signals on those received directly from the ship. In ranges where both antennas are fixed, the phase and magnitude of reflections are controllable and measurable. In an antenna range for shipboard measurements, however, the antenna under test is moving which will add complexity because of the changing geometry of reflected radiation, [Ref. 5].

By electromagnetic theory the strongest reflections will occur from metallic surfaces or conductive lines parallel to the polarization of the radiation; therefore, a range in close vicinity of industrial buildings constructed with sheet metal must be avoided. Other buildings will have similar characteristics with the added difficulty produced by currents induced in inclined conducting members which will cause radiation components of quadrature polarization. Trees will have a smaller reflection coefficient, but they are still an error source. Power lines

will affect measurements in horizontal polarization more than in vertical.

In the design of a range for measurements of shipboard antennas these effects must be minimized. A variety of techniques can be used. The reflections from objects can be minimized by making the recording antenna[1] insensitive to radiation from those directions. This can be done by using the directional characteristics of certain antennas or by isolating the recording antenna. Isolation can be physical, i.e., locating it at large distances from reflecting sources, or by placing the recording antenna in a cubicle. Three sides and the top of a cubicle are shielded which attenuates waves coming from those directions. The inside of the cubicle is covered with absorbing material in order to have a reflectionless surface for waves coming from the open side. The recording antenna then can be affected only by sources in the measurement area. The cost of the absorption material may be prohibitively high for such a cubicle, especially in low-frequency regions.

Directional recording antennas are a possible solution of the problem of reducing reflections from objects on the shore. Reflections will be restricted to the side lobe level. Additional problems are created, however, by the increased size of the arrays and the number of arrays required, by the limited bandwidth, to cover the frequency spectrum.

Noise Sources. Man-made sources have a high level in

[1] This term is used for the antenna other than the antenna under test.

industrial areas. This restricts low-level measurements. Areas close to naval shipyards must be avoided. A noise survey of selected areas is necessary. Concern for noise is more important for low-level measurements of ECM equipment, electro-magnetic interference values and underwater tests as planned in advanced phases of the range. Man-made noise in radio frequencies is proportional to the population to some degree.

Geographical Factors in Ship Maneuverability. Each particular antenna under test is surrounded by different regions such as near field, far field, and defined by different boundary conditions depending on its design. To have a uniform phase front, distance criteria can be established for antennas which are short as compared to a wavelength and for antennas which are long as compared to a wavelength. To make antenna measurements in a far region where the angular field distribution is essentially independent of the distance from the antenna the following criteria is given for distance:

$$R = \frac{2d^2}{\lambda}, \text{ where} \tag{1}$$

d is the longest dimension of the antenna. In cases where the antenna is mounted on a vehicle the currents induced in the structure of the vehicle may require using a value of d larger than the actual dimension of the antenna itself. When recording antennas are located at the edge of water, the geographical characteristics of the seaward side must be convenient for ship maneuverability. Whenever the lower level of measurements permits, this distance must be as large as possible to minimize the

parallax errors on the station bearing from the ship.

Ground Reflections. Ground reflections and their effects on antenna measurements have been investigated by many authors,[Refs. 4,5]. Most of these studies have been made for off-site measurements of antennas. In the case of measurements of shipboard antennas, control of the ground path between antennas is restricted. Due to the height of the shipboard antenna relative to the recording antenna, the main reflections are governed by sea path or ground path. This is shown in Fig.1:

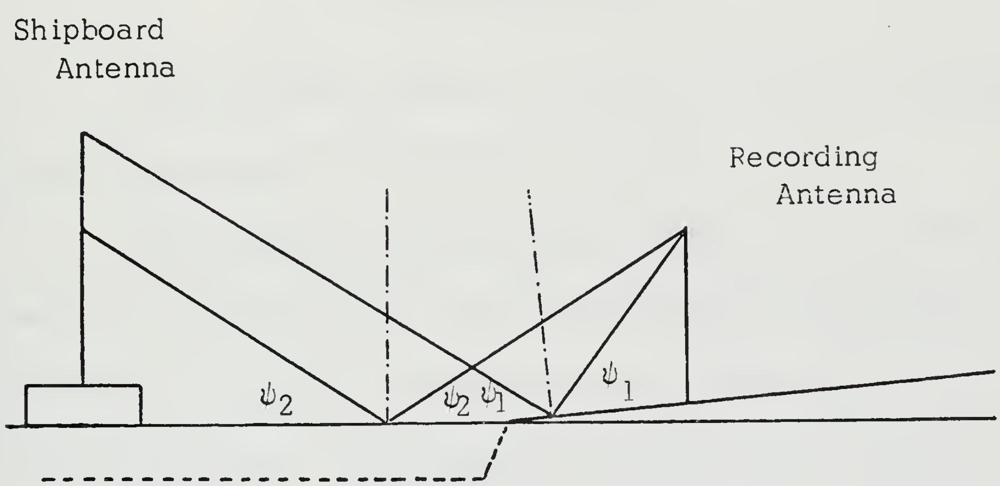


Figure 1. Reflections from ground and sea

The intensity of ground reflections on the recording antenna depends upon the reflection coefficient. This is a function of angle of incidence, relative permittivity and conductivity of the media, frequency used, and type of polarization.

For vertical polarization, reflection from a plane media is given by Ref. 3.

$$R_v = \frac{(e_r - jx)\,\mathrm{Sin}\,\psi - \sqrt{(e_r - jx) - \mathrm{Cos}^2\,\psi}}{(e_r - jx)\,\mathrm{Sin}\,\psi + \sqrt{(e_r - jx) - \mathrm{Cos}^2\,\psi}} \qquad (2)$$

$$= |R|\, e^{\angle R} \qquad (3)$$

where

e_r = relative dielectric constant of media

ψ = incidence angle

σ = conductivity mhos/m

For an antenna range the amplitude and phase of reflected waves must be estimated at the recording antenna.

Choosing the recording antenna position at the edge of the water leaves a reflection path to only one medium for which electric characteristics are known. This becomes more complex with the changing of the surface by waves. This results in one advantage, however, in that reflections will be less in the direction of the recording antenna.

The following criterion has been given by Rayleigh and is applicable to electromagnetic waves as given by Jasik [1]. By this limitation, when the height of waves satisfies the following inequality, the medium is considered rough; the distribution of reflected waves is more uniform and at an amplitude relatively less than in the case of a smooth surface.

$$h > \frac{\lambda}{8 \text{ Sin } \psi} \quad (4)$$

where

$$h = 0.0048 \; V^{5/2} \quad (5)$$

for a given wind speed V (by Urick, [6]).

and ψ = incidence angle.

For low frequencies λ will be greater. In addition, Sin ψ is restricted to a maximum value. For low frequencies, then, extreme values of heights are necessary to achieve a rough plane criterian. Therefore, the sea surface can always be considered as a smooth plane in communication measurements.

B. PLAN OF THE RANGE

At this point a plan for the range can be given. The ground for this range will be chosen in a remote area where the ambient noise level is low. Recording antennas will be directional to minimize reflections and will be placed close to the edge of water. Adequate maneuvering area must be available seaward of the range location. There must be navigational aids, and there should be little or no sea traffic, Fig. 2.

C. MEASUREMENTS AND EQUIPMENT

In the first phase of the range design, measurement of shipboard antenna field patterns will be achieved. For different types of antennas, the following setups are selected;

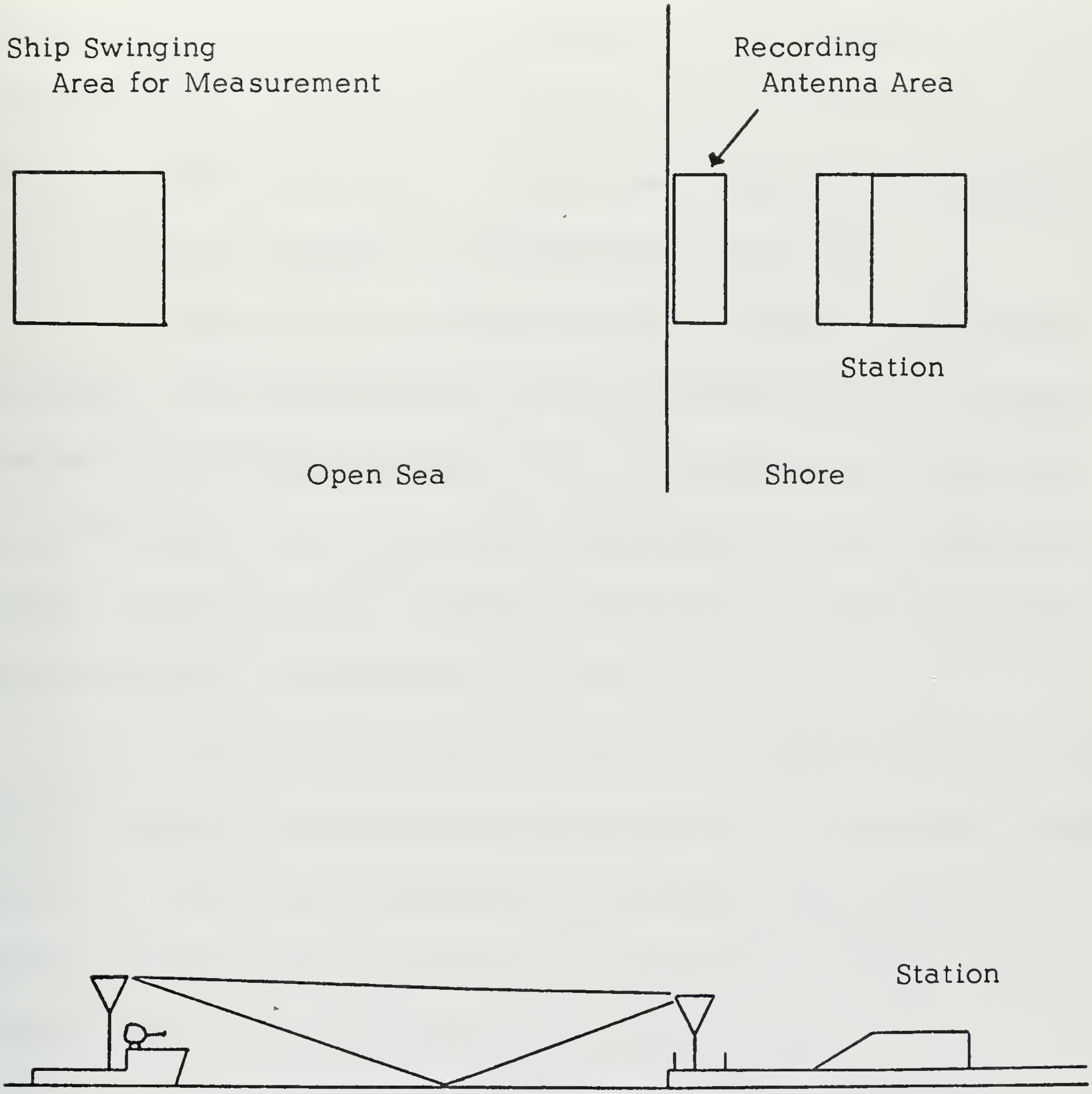


Figure 2. Basic geometry of the antenna range

1. Transmitter Antennas

For measurement of patterns of transmitter antennas on board a vessel, two equipment setups are necessary. One is required to measure the field strength received at the recording antenna while the other is required to sense and transmit the ships heading relative to this antenna.

a. Measurement of Field Intensity for Recording

There must be suitable equipment on shore to measure field intensity. In the communication frequency spectrum, there are available commercial field intensity meters in MF, HF and UHF bands. The high cost of FI meters made it necessary to find another relatively inexpensive method. A receiver having a voltage controlled R.F. input attenuator was selected, [Ref. 7]. Configuration of this setup is given in Fig. 3.

Measurement of field intensity in an antenna range does not require equipment of high sensitivity because the ship will be very close to the range. These measurements also do not require long term stability since each measurement is of relatively short duration and the calibration of the equipment can be checked between measurements.

Field intensity meters available today have responses directly proportional to field intensity at the probing point. In a communication superheterodyne receiver this function is not inherently linear. With a feedback circuit, however, the input to the receiver can be maintained at the same level during the measurement. The attenuation value of this feedback will be as linear as the response of the attenuator to its control voltage.

The functional description of the elements in this technique of field intensity measurement is as follows: (refer to Fig. 3)

(1) Voltage Controlled Attenuator. This is a resistive attenuator (in HF range employing field effect transistors and in higher frequencies PIN diodes) controlled with bias voltages which are supplied from the controller for logarithmic attenuation.

(2) Receiver. A standard Navy receiver which covers the frequencies of interest is necessary for the measurement. This receiver must accept the modulation methods available in shipboard transmitters.

The receiver must have short-term stability, at least for the time required for a single run. In other words, the receiver must maintain the same gain level during one measurement. The minimum gain of the receiver is restricted by the lowest level of field intensity required for plotting.

(3) Comparator. The audio output of the receiver is fed to the comparator. The outputs of typical Navy receivers are in a frequency range of 300-3300 Hz, and supply 0-3.5 Vrms to 600 ohms. In these measurements this will always be a sine wave. The input signal to the comparator will be rectified; the signal will then be compared with a variable reference level. The reason for a variable reference level is twofold:

(a) To take care of long-term instabilities.

(b) To compensate for the gain of different receivers used.

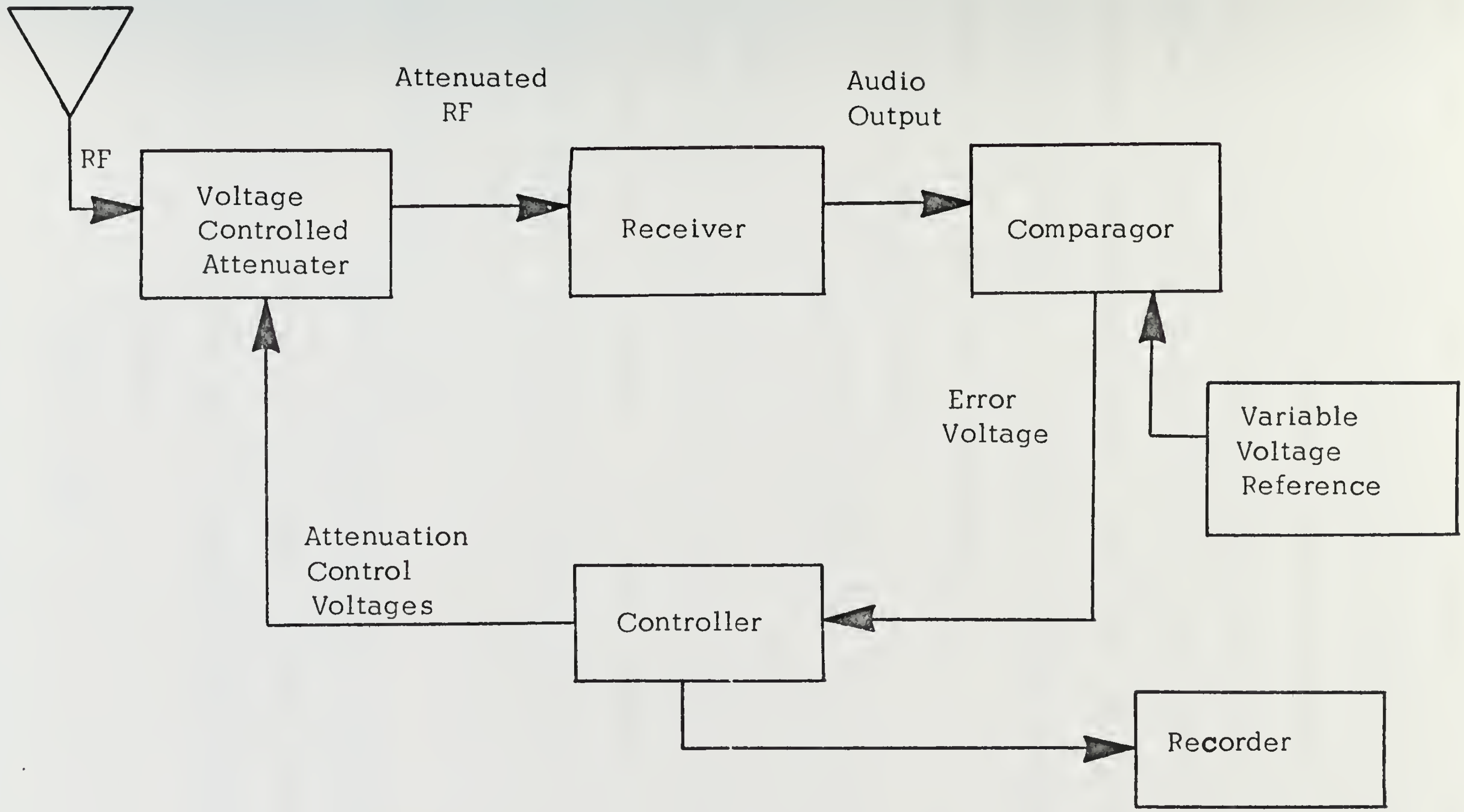


Figure 3. Basic functional diagram of field intensity receiver

(4) Controller. The necessary voltages to control the attenuators will be generated by this component. The output of the comparator, which is a slowly changing DC voltage proportional to field intensity, will be processed with operational amplifiers to generate proper control voltages for the voltage controlled attenuators. This method will adjust the receiver to the same level of output within the range of the attenuator. The signal strength is then always proportional to the control voltage of the attenuator. Logarithmical values are obtained when the response of the attenuator is logarithmic.

b. Angle Information

(1) Type of Angle Information. For horizontal patterns of shipboard antennas, the relative bearing of the probing point from the vessel must be known at the shore station in order to generate patterns as a function of this direction. This angle information is available from the gyro compass on board as true heading of the ship. This information can be obtained as single-speed three-wire synchro information from any gyro compass repeater station.

When the true ship course is subtracted from the true bearing of the probing point, the relative bearing of the recording antenna is obtained. As shown in Fig. 4, these two angles can be called, respectively, $\widehat{NR}$ and $\widehat{NS}$. Therefore,

$$\widehat{RS} = \widehat{NR} - \widehat{NS} \tag{6}$$

Plots will be obtained of field intensity versus $\widehat{RS}$,

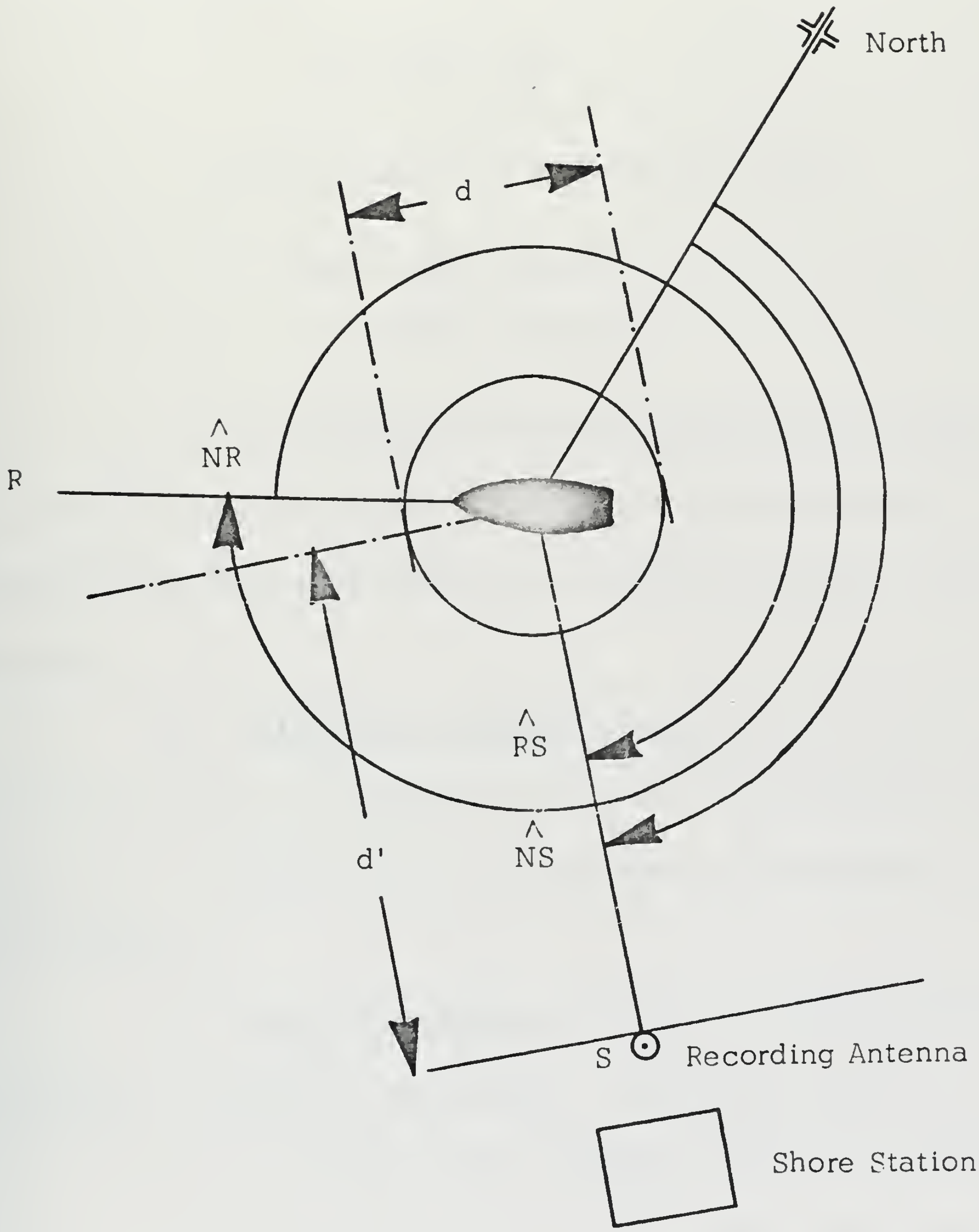


Figure 4. Angle relations for pattern measurement of communication antennas

which is the relative bearing of the shore station. The angle $\hat{NS}$ is almost a constant angle and the maximum change of this angle is the tangent of half of the perpendicular swinging distance over the shortest distance during the measurement

$$\tan^{-1}(\hat{NS}) = \frac{d}{2d'} \quad . \tag{7}$$

As an estimate, d' = 4Km and d = 200 m:

$$\tan^{-1}(\hat{NS}) = 0.025$$

$$\hat{NS} < (1^{\circ}\ 30')$$

If an angle less than this is required, this information can easily be obtained from one of the surface gunfire directors. For an accuracy of less than a half degree, an independent system will be necessary.

(2) Telemetering of Angle Information. To send the above information to shore, the information must be extracted from the synchros, transformed to a suitable form for transmission, and telemetered with proper equipment.

(3) Form of Information. There are many available forms of information suitable for transmission. Pulse code modulation using binary code has been selected using available shaft angle-to-binary encoders. It is expected that this will produce fewer errors in the transmission and will be adaptable to future computer interface.

It is planned to assemble a small portable box with 3-wire single-speed synchro input and coded binary angle information

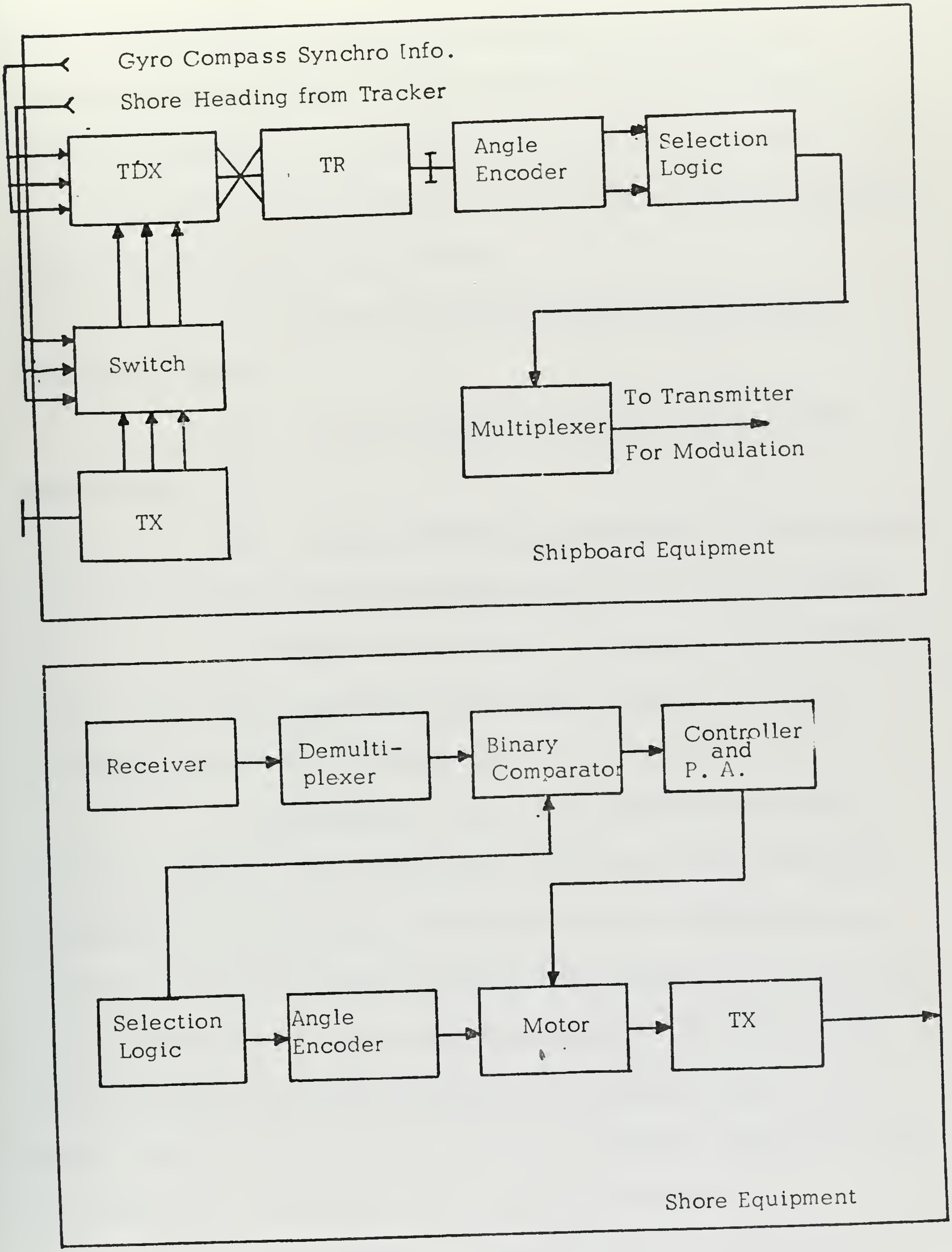


Figure 5. Functional diagram for angle telemetry system

output. This box will be carried aboard the ship and plugged into a gyrocompass repeater outlet. The output will be used to modulate a shipboard transmitter for transmission of the coded angle information to the range station. In future phases, a small portable telemetry transmitter will be designed for the following reasons:

i. Bandwidth requirement (shipboard transmitter is restricted to 3 KHz).

ii. It will not depend on the ship equipment performance status.

iii. A similar battery-type transmitter will be necessary for elevated probing-point measurements in the vertical plane (Phase II).

A functional description of the telemetry system shown in Fig. 5, for angle information is given below. Detailed circuitry of this system will be given in Chapter VI.

Synchro Units. One control differential transmitter (TDX) and a synchro receiver (TR) will be used in this unit. Addition or subtraction of two angles can be obtained with these synchro elements, [Ref. 8]. The relative direction of the recording antenna can be generated in this unit using the 3-wire single-speed synchro information from the ship gyro compass and the true bearing of the recording antenna from an optical tracker. This latter angle can also be manually applied by synchro transmitter (TX). The output will be a single shaft angle.

Angle Encoder. A commercial type encoder with at least one-half degree resolution will be used. For a PCM circuit the

dominant error is the quantization error. This resolution corresponds to at least 10 bits for 360°. The use of more turns for 360° does not give more resolution bits per degree. Therefore, angle position will be sensed with the encoder, and parallel switch positions will be fed to selection logic to generate the proper parallel binary code.

<u>Selection Logic</u>. This part of the system is used to obtain the binary code of angle position without any ambiguity error caused by brush configuration. The output will be 13-digit parallel binary.

<u>Multiplexer</u>. This unit is used to convert available binary information to the series form. Bit rate is adjusted to a speed suitable for the handling of a bandwidth of 3200 Hz (including 3 harmonics of the clock) and also a frame pulse is inserted for frame synchronization. RZ code is selected for the form of the binary pulse train. This information is fed to a TED transmitter through a 600-ohm input resistance.

<u>Transmitter</u>. As has been explained before, this will be an AM transmitter in the UHF range. A representative TED transmitter has a 300-3300 Hz bandwidth for 3-db-down points, and 600 Ω input resistance to the modulator which can be easily matched with the output of a medium-power buffer gate. For a portable transmitter, FSK will be more suitable to obtain higher bandwidth and consequently a higher rate of data transmission.

The receiving equipment includes a receiver, proper equipment to obtain continuous binary output, and a digital servo circuit to convert binary information to angular position. These components have

the following functions:

Receiver. Any UHF receiver compatible to the TED transmitter, e.g., an AN/URR 13 receiver, will be used because of the availability of this equipment. The output of the signal will be conditioned for logic circuits.

Demultiplexer. This unit first generates impulses for bit synchronization of the clock, then generates another code for frame synchronization. The latter code controls the counter. The sequence pulses generated from the counter output are used for series to parallel conversion. A sample and hold circuit keeps information between two successive frames continuously.

Comparator. This unit compares the binary position of the incoming signal with the binary position of the servo motor, and generates weighted error voltages. If the values of the incoming information are higher then the servo motor values, this voltage goes into a ladder. If the bit position for the servo motor is higher, the voltage goes to the other ladder. Then the output at each ladder is weighted to a sum which corresponds to higher states.

Control Voltage Generator. This is an IC comparator which compares two voltages at the output of the two ladders of the comparator, and generates a voltage or zero level for direction control of the servo motor.

Motor and Power Amplifier. The motor is driven with a solid state amplifier using a bidirectional current. The sign of the

current is governed by the control-voltage generator output.

The angle encoder and selection logic are duplicates of those in the transmitter circuit.

c. Required Number of Setups

The measurement time will depend on the number of turns carried out by the vessel, and this number is an inverse function of the number of available measurement sets. Each set is considered to consist of an appropriate measurement antenna or antenna coupler output, and a receiver with a voltage-controlled attenuator.

If the number of recorders available is less than the number of measuring sets, the number of turns will depend on this quantity.

The maximum number of one kind of antenna is assumed to be 5 (for UHF in a destroyer). Therefore, it is planned to have one angular telemetry set, three measurement sets and three recorders to cover MF, HF and UHF transmitters. With this equipment, the ship must make ten complete turns to obtain one pattern at one frequency for each of the antennas. If the number of antennas is less than the maximum assumed the number of turns required will, of course, be correspondingly less. If additional recorders and measurement sets are available the ship maneuvering time will be further reduced.

The complete setup for ship transmitter antenna pattern measurements is shown in Fig. 6 and in Fig. 7, 8.

2. Shipboard Receiver Antennas

To measure and record the patterns for the antennas used on

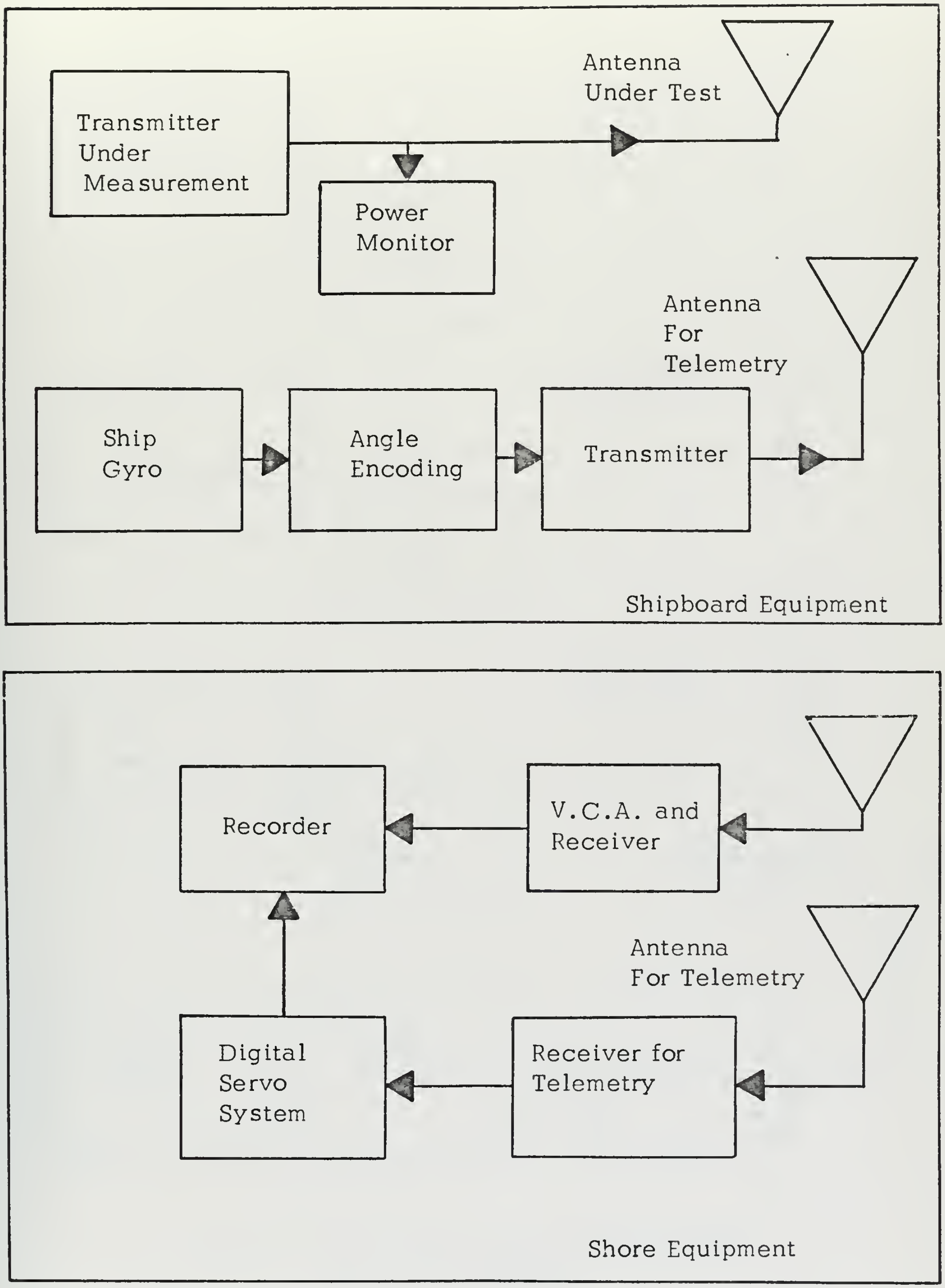


Figure 6. Transmitter antenna measurement in a single band

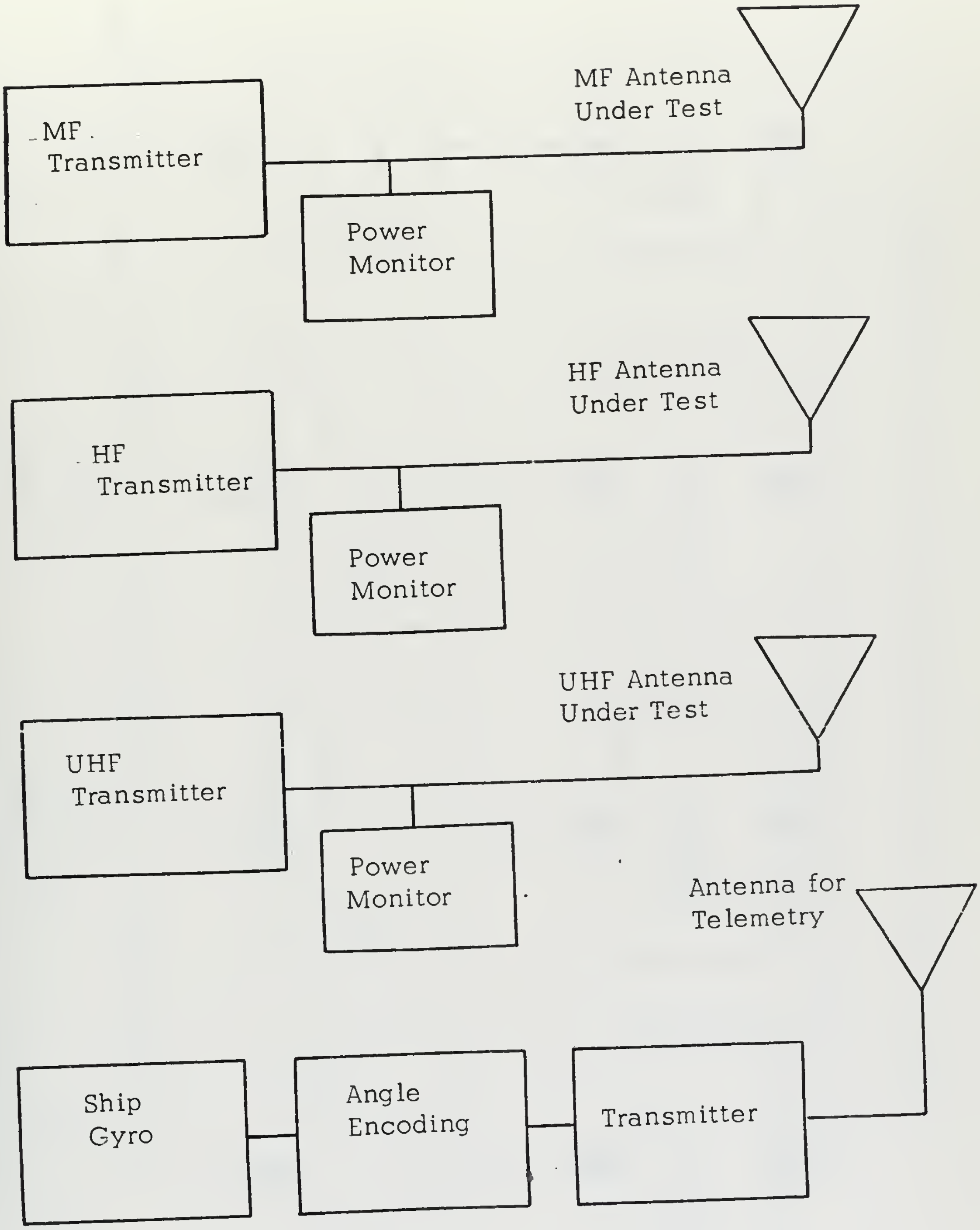


Figure 7. Transmitter antenna measurement setup on shipboard

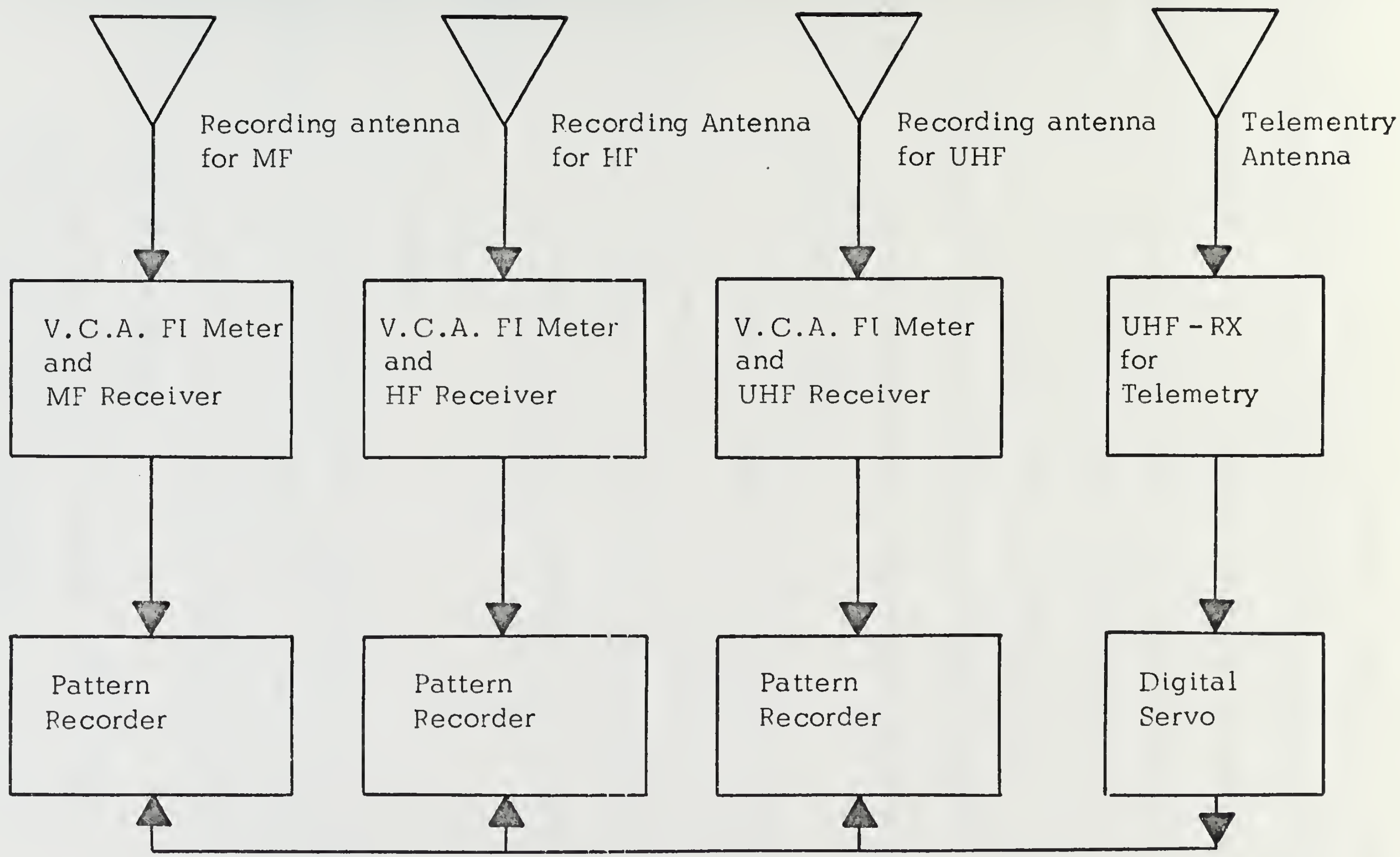


Figure 8. Shore station setup for transmitter pattern measurement

shipboard for receiving, a technique similar to that used for transmitting antennas will be employed. Since the situation is reversed, a signal from shore will be picked up by the antenna under test and sent to a shipboard receiver. This receiver will have a voltage-controlled attenuator between the antenna and the receiver input. The output of the attenuator controller will be converted to digital signals and multiplexed with angular information; they will then be transmitted ashore with the same telemetry transmitter.

The equipment for obtaining receiver antenna radiation patterns is shown in Fig. 9, and its functional characteristics explained below.

a. Field Intensity Meter

The same method as before will be employed and the difference in gain levels between ships will be corrected by adjusting the reference level of the comparator. One receiver will be used for each frequency range so that the performance of antennas in each band can be compared easily.

b. Telemetering

This is the only equipment which differs in the method of handling information from that used in transmitter antenna measurement. The telemetry system will have an 8-channel multiplexer; these channels will carry the following information:

1) Word synchronization signal
2) Angular information
3) MF field intensity information
4) HF field intensity information
5) Angular information
6) UHF field intensity information
7) Spare
8) Angular information

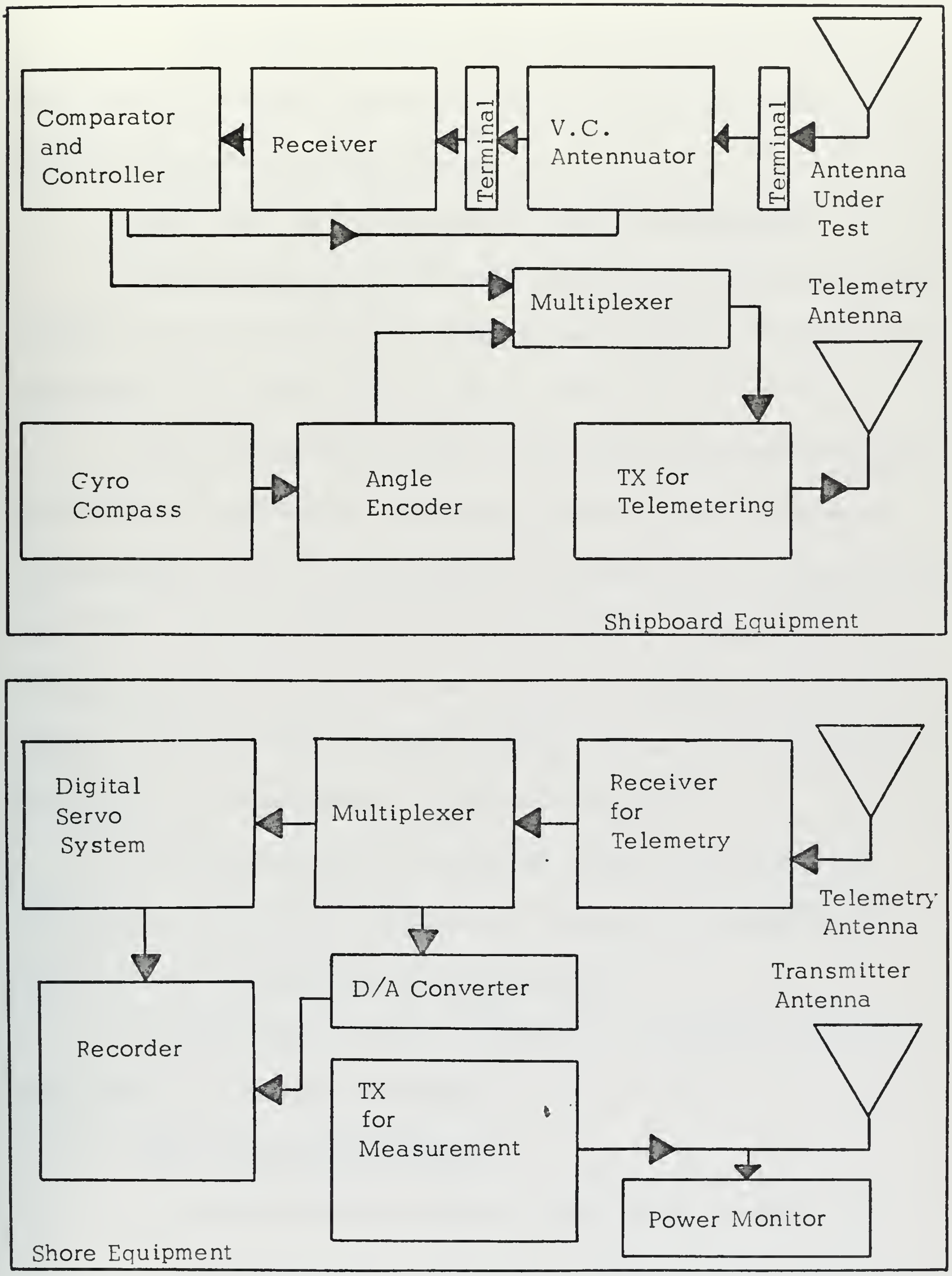


Figure 9. Receiver antenna pattern measurement setup

The spare channel can be used for other information or to send more field intensity information. This circuitry can be added to the angular telemetry with a switchboard.

3. Shore Setup for Communication Pattern Measurements

The shore setup will need other monitoring equipment and meters to make absolute field intensity radiation measurements. A possible room arrangement at the shore station is given in Fig. 10.

One of the important problems in the shore station will be interference between equipments, especially with regard to electromagnetic compatibility. If it is not possible to find another room or building for the transmitter, this part of the room must be shielded. Another solution is to make receiver and transmitter measurements at different times. For absolute measurements, RF signal generators are necessary to calibrate the receivers and their voltage-controlled attenuators.

The Control Desk will have proper displays for the state of equipment to ensure that the technician in charge of measurement will avoid making time-consuming elementary errors.

In future phases, all the controls can be brought to this point except for paper changing of recorders.

4. Radar Antenna Measurements

a. Relations between Antenna Scanning and Recording Speeds

In a radar antenna, the rate of change of field intensity with antenna angle is much greater than with an omnidirectional antenna because of the highly directional character of the antenna. Therefore, to

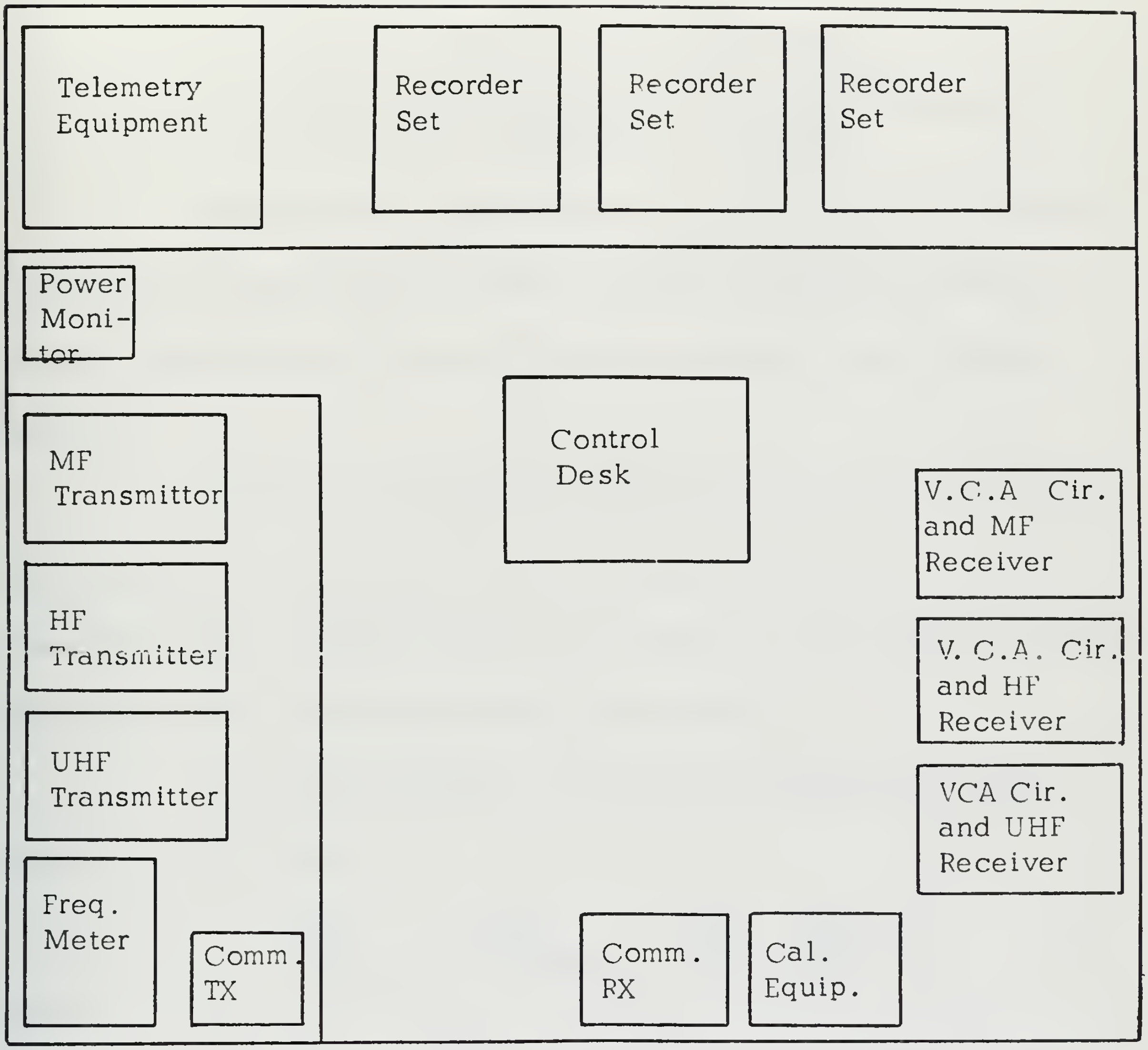


Figure 10. Room setup for communication pattern measurement

select a method for shipboard radar antenna pattern investigation and to design a system to measure the characteristics of radiation pattern information, the following parameters must be considered:

i. Scanning rate of the radar under test
ii. Approximate beam shape of radar pattern
iii. Other signal characteristics of radar for detection
iv. Time for one complete turn of the ship

The antenna pattern measurement can be made in a simple way with the antenna fixed in a relative bearing and while the ship is turning. This gives the pattern of shipboard antennas in one relative direction.

To obtain more accurate information about the performance of the antenna it is necessary to look in successive relative directions around the ship. This information can be obtained, with the proper method, while both antenna scanning and ship maneuvering.

The relation between the above parameters and recorder response is as follows:

$$\left(\frac{dE}{d\theta}\right)_{max} \leq \left(\frac{dM}{dt}\right)_{max} \cdot \left(\frac{d\ell}{dt}\right) \cdot \left(\frac{d\theta}{dt}\right)^{-1} \qquad (8)$$

where

$\left(\frac{dE}{dt}\right)_{max}$ = maximum rate of change of field intensity

$\left(\frac{dM}{dt}\right)_{max}$ = maximum rate of change of amplitude value which can be plotted on receiver

$\left(\frac{d\ell}{dt}\right)$ = speed of the recorder

$\left(\frac{d\theta}{dt}\right)$ = antenna scanning rate

The limitations of continuous recording can be overcome by employing a cathode ray tube of an oscilloscope or a converted radar scope. The choice between the two will be based on time responses and coordinate systems.

b. Necessary Angle Information

On shipboard, the antenna position will be obtained from a synchro system, because generally in all radars, antenna positions (true and relative and true compass heading) are available in 3-wire single-speed synchro outputs. Available angle relations are shown in Fig. 11. It is necessary to study these relations in order to derive the ones needed for plotting.

Aboard the vessel, available angles are as follows:

$\widehat{NR}$: True heading of the ship (available at ship)

$\widehat{NA}$: True direction of radar antenna (available at ship)

$\widehat{NS}$: True bearing of shore station (available at ship)

$\widehat{RA}$: Relative position of the antenna (available at ship)

$\widehat{SA}$: Position of the antenna relative to shore station

As in previous measurements, $\widehat{NR}$, the true heading of the ship and $\widehat{NS}$, the true bearing of the shore station are used. $\widehat{SA}$ for plotting of the radar antenna is also necessary. This information can be generated with an additional synchro control differential transmitter at the ship.

$\widehat{NS}$ is almost a constant angle and can be applied to CDX

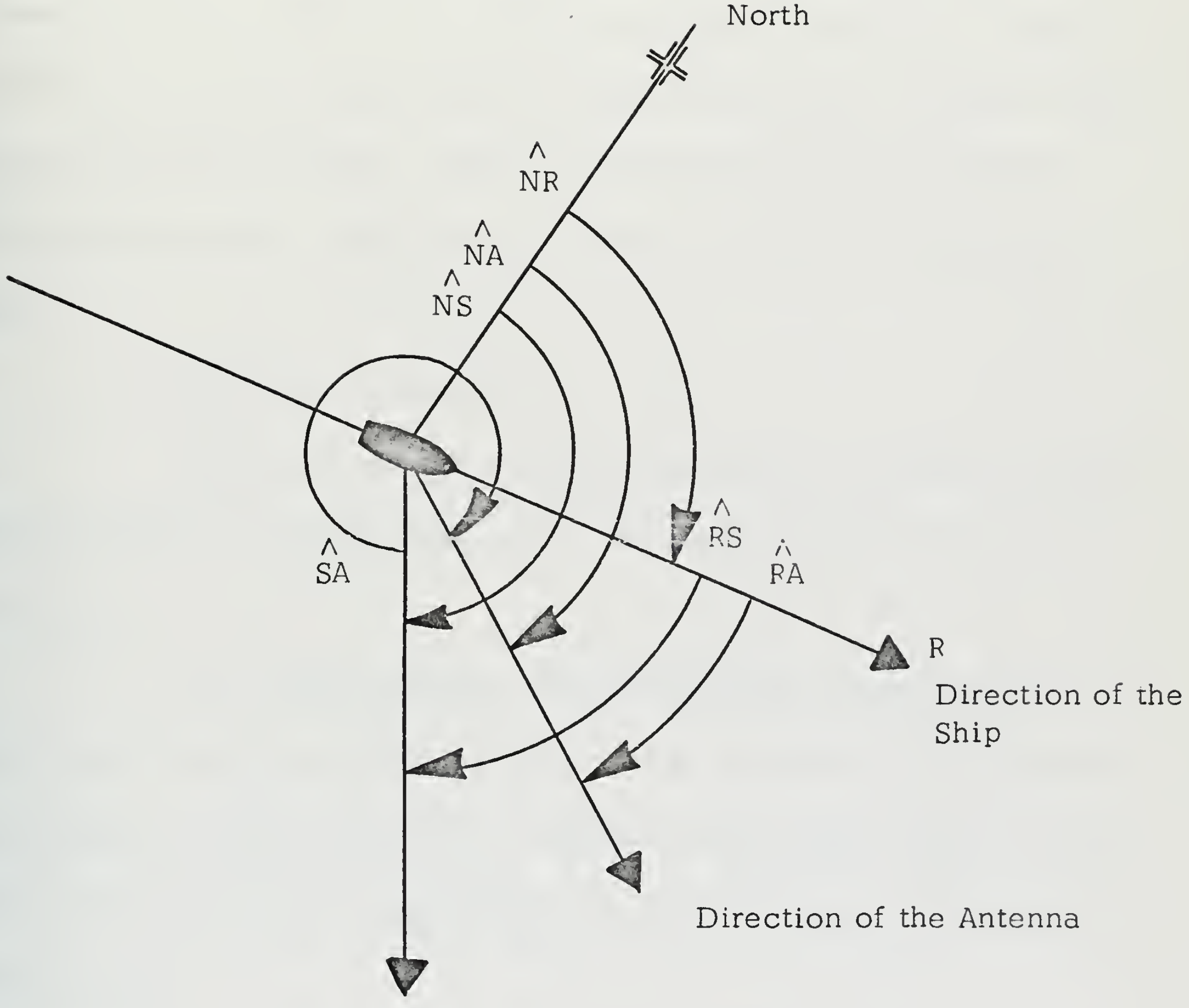


Figure 11. Angle relations for radar antenna pattern measurements

before measurement; radar plots can then be made for field intensity versus $\hat{AS}$.

$$\hat{AS} = \hat{NS} - \hat{NA} \tag{9}$$

These two angles can be subtracted at TDX. This is shown in Fig. 12. When $\hat{AS} = 0$, the beam will be directed to the shore station and the binary output of the encoder will be zero. In order to get the usual pattern recording, 180° must be subtracted from or added to $\hat{TR}$ output value; this can be done by mechanical alignment of the encoder.

c. Measuring Equipment

Shipboard and shore station equipments and their functional characteristics are explained below. The complete setup is illustrated in Fig. 13.

(1) Synchro Circuit. Shipboard angle encoder sets will have synchro control differential transmitters for addition and subtraction of bearings previously explained. Therefore when proper angles are supplied to these sets, the output will be the required angle information for transmission.

(2) Angle Encoder. The angle encoder will have the same configuration as before. The only difference will be in multiplexing, since there is one more angle for transmission, that is the relative bearing of the shore station. This angle is obtained in exactly the same way as in omnidirectional measurements.

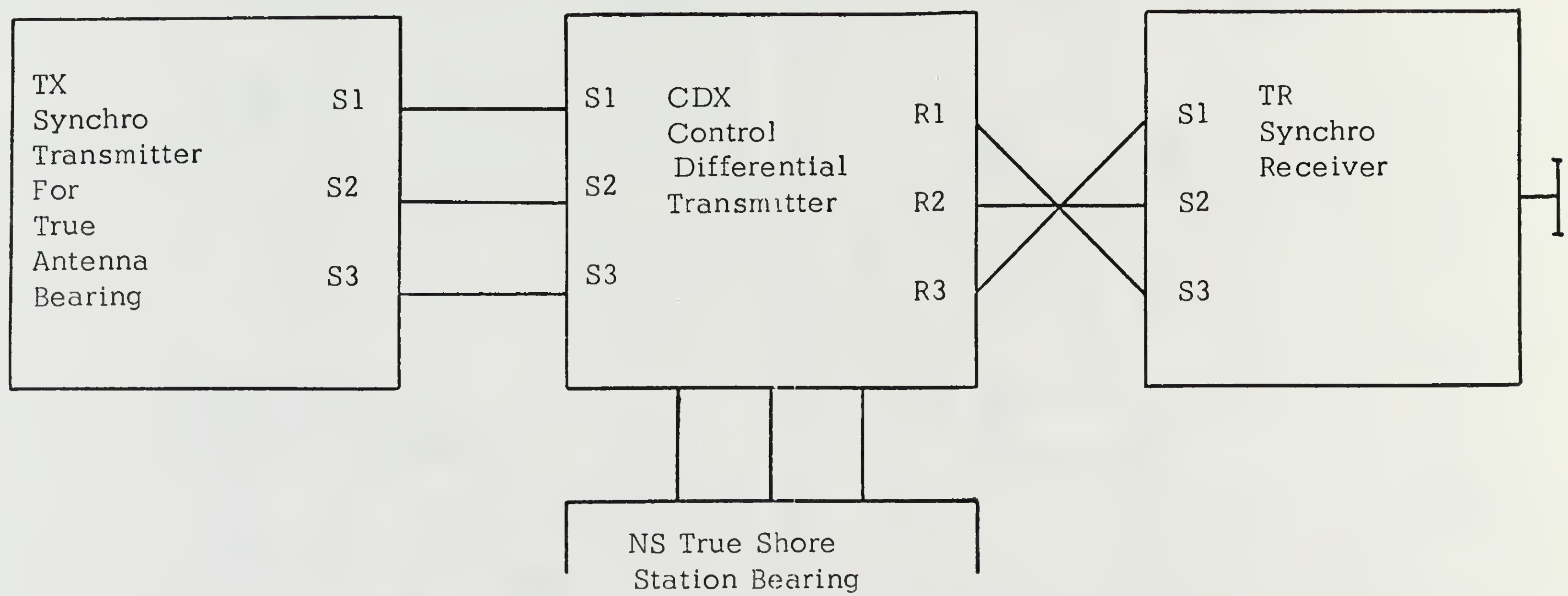


Figure 12. Obtaining antenna bearing relative to shore station

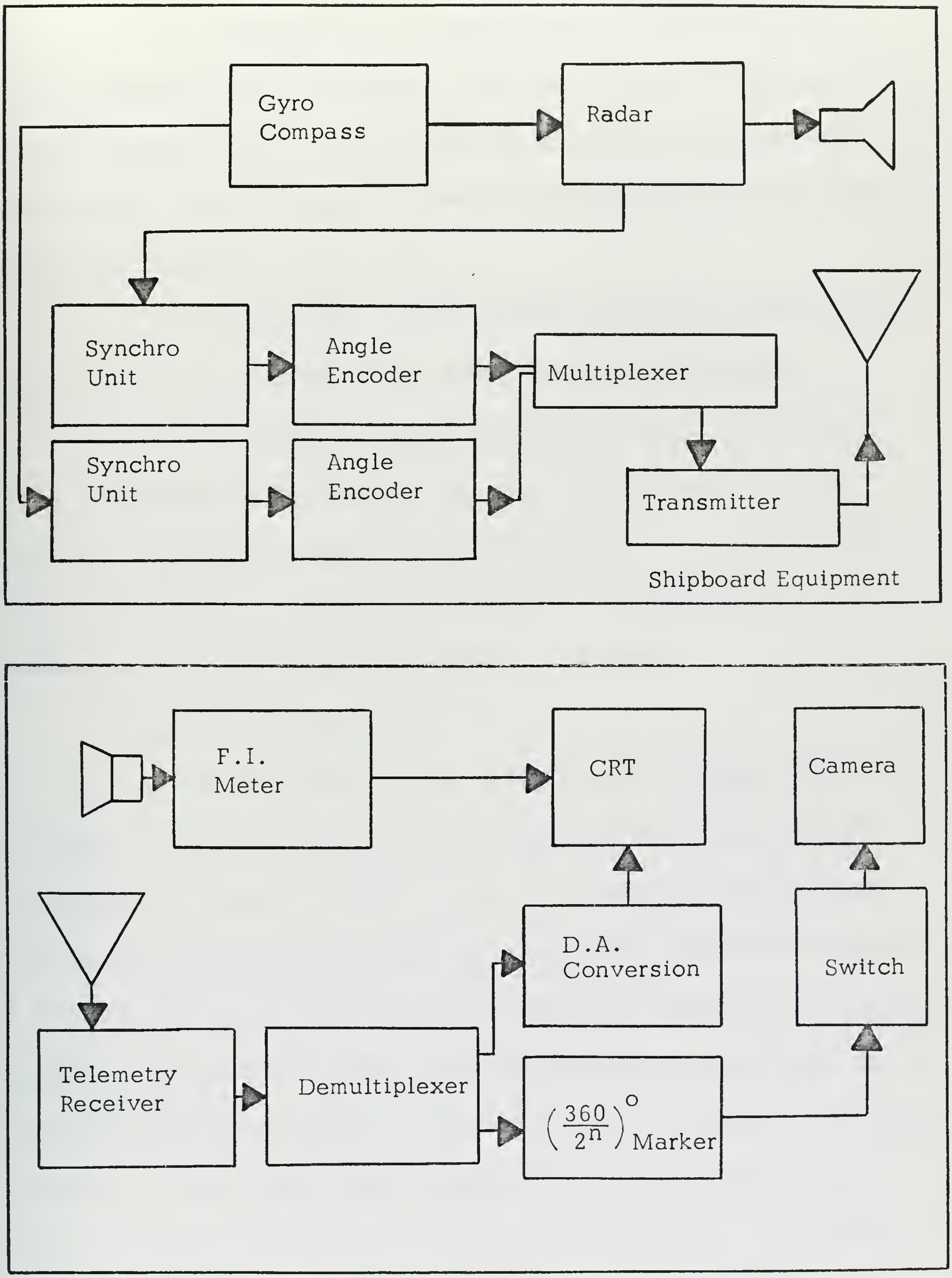


Figure 13. Setup for radar antenna pattern measurement

(3) Multiplexer. A seven-channel multiplexer will be used for transmission of angles; four channels of this multiplexer can be given to antenna rotation and the other three to relative bearing of the shore station. As an alternative, two separate encoders with two transmitters can be used.

(4) Transmitter. The transmitter will be the same as used in omnidirectional communication antenna pattern measurements.

(5) FI Meter. A superheterodyne radar receiver will be used. In configuration is given in Fig. 14. In superheterodyne configuration, a klystron, mixer, proper local oscillator, IF amplifier, and crystal detector will be sufficient. Calibration of this equipment will be made with an additional calibration signal generator.

5. Boresight Measurements

Most of the tracking radars in naval ships are based on conical scanning. In these antennas, precise determination of beam axis with optical sights is required. The first axis is called electrical boresight and the second one is used for reference. A method must be designed for the error caused by angular deviation of electrical boresight from reference boresight. In conical scanning, the single beam scans circularly around the electrical boresight when a receiving antenna is locked to the reference boresight; if there is any error, received RF energy is modulated with a signal at the same frequency of scanning. The strength of this error is proportional to the angular displacement of electrical boresight from reference boresight.

For alignment of these two axes, the field intensity meters for radars can be employed. Modulation of video signal can be observed with an oscilloscope and then adjusted to zero by moving the reference optical sight horizontally.

D. RECORDING ANTENNAS FOR RANGE

1. General

One important point remains in this chapter which is related to all the subjects under consideration and that is the selection of antennas suitable for reception of the signals whose field intensity is to be measured and recorded. The factors to be discussed in detail later, which are of prime importance, are directivity, bandwidth and size.

2. Existing Field-Intensity-Meter Antennas

Most existing types of field strength meter antennas are: adjustable half-wave dipole, loop antenna, and horn antenna. These are generally attached to the portable field intensity receivers and are not considered suitable for a permanent range installation.

3. Recording Antennas for Antenna Range

For probing field intensities in this range, antenna requirements are as follows:

a. Frequency

Communication antennas can be divided into three measurement ranges: MF, HF, and UHF. Corresponding frequencies for these ranges are:

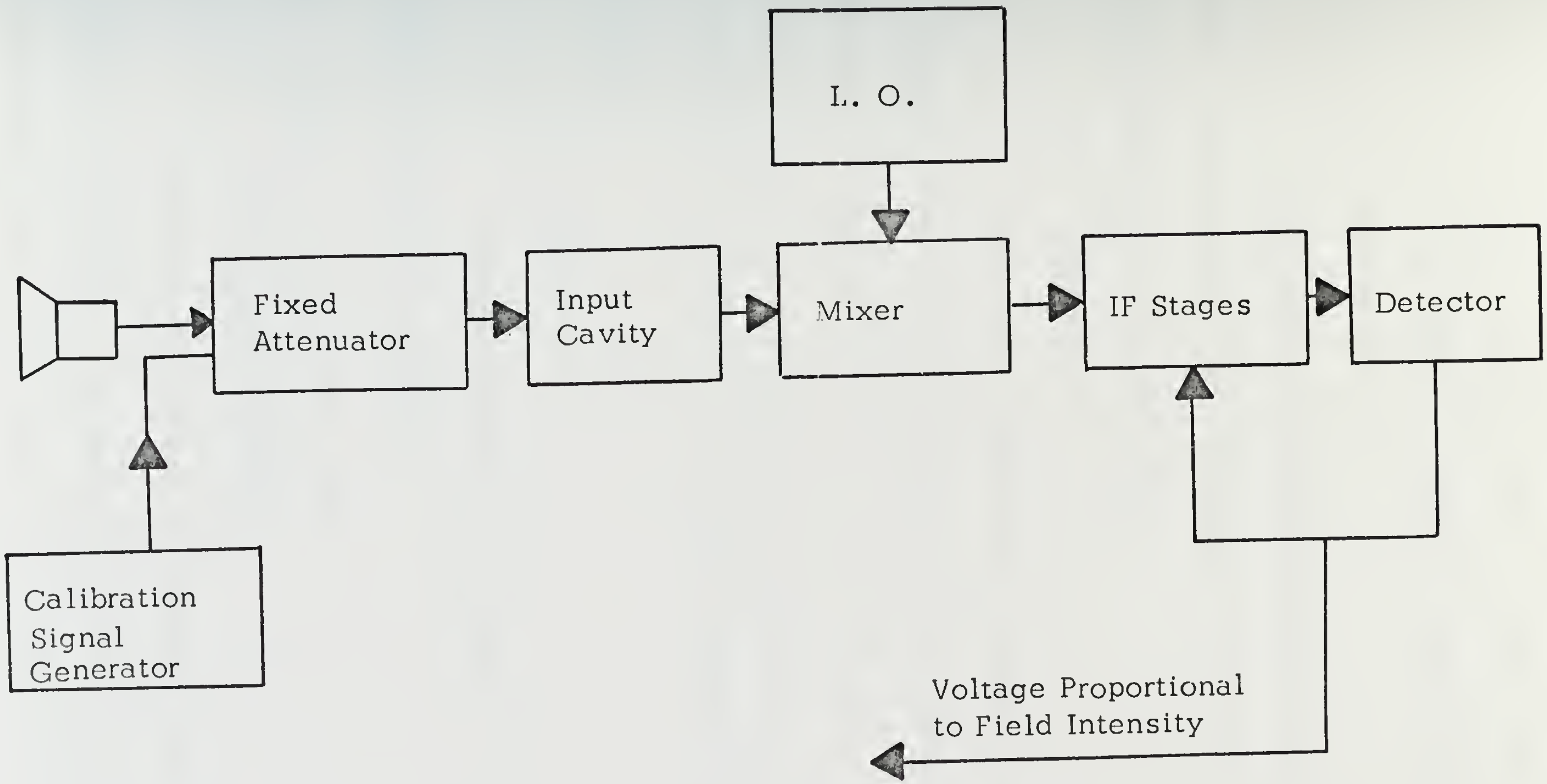


Figure 14. Field intensity meter for radar measurements

405 - 535 KHz	MF	Including radio DF and distress
2 - 30 MHz	HF	Ship to ship, ship to shore
225 - 400 MHz	UHF	Ship to ship, UHF
1 - 10 GHz	Radar	Including IFF

b. Bandwidth

In order for recording antennas to cover the frequencies above, antennas with wide bandwidth are necessary. This can be achieved by employing periodic type antennas.

c. Directivity

The design of directive antennas is an easier task in UHF and above. It is a more complicated task in lower frequencies and it is necessary to trade off directivity with bandwidth. For recording antennas at this installation, low side-lobe level and back-to-front ratio are important for minimization of reflections from the side and rear of the antenna.

d. Size

Compact antennas are necessary in order to keep the supporting structure at a minimum.

E. RESULTS OF MEASUREMENTS

1. Communication Patterns

Current and previously measured patterns can be compared and changes investigated. Undesirable notches and low levels of radiation in omnidirectional antennas are significant to communication efficiency and must be known by communication personnel. A second result is that

comparison between patterns permits the best communication antenna to be found. This information must then be presented to the ship's forces in a form to enable them to select the best antenna for a given frequency, equipment and direction of the other station. A third result is that the power output and efficiency of the antenna can be anticipated.

2. Radar Patterns

Similar results will be obtained with radar patterns. First, the maximum power output of the antenna will be known. Second, side lobes can be checked relative to the main lobe. Third, the correct position of the feed horn can be identified. Fourth, any misalignment in the transmitter and any mismatches after repairs can be adjusted.

3. Boresight

With this measurement, careful alignment of electrical boresight of the tracking radars can be made relative to visual boresight.

III. PHASE II OF THE RANGE

A. INVESTIGATIONS OF METHODS FOR PHASE II

This part includes theoretical studies for development of the range for more complete measurements. The objectives as explained in Chapter I are:

1. Investigation of Pattern Measurements

Investigation of pattern measurements in the vertical plane must be investigated. The principal reasons are as follows:

Gain versus elevation angle is important for over-the-horizon communication in HF links.

For air search radars the location and depth of the notches is of great importance.

There are many methods proposed for vertical plane measurement, [Refs. 9,10,11]. The following items are used as elevated platforms for the recording antennas: 1) aircraft; 2) helicopters; 3) captive balloons.

Several of these are not practical for this type of antenna range. An important practical consideration in the first two is cost and the difficulty in tracking. The third, a captive balloon, is less expensive and may be used as an elevated platform to carry the recording antenna.

Advantages of captive balloons are:

i. The platform itself is inexpensive. Meteorological balloons may be used. (Lifting capacity is important).

ii. Relatively no operating cost.

iii. Easy to handle with inexperienced personnel.

Disadvantages of balloon platforms are:

i. Necessity of designing a transmitter and light weight field intensity meter with integrated power supply.

ii. Station keeping and control of direction are difficult, particularly with high winds.

iii. Maximum height is restricted because of weight of captive lines.

iv. There is no access to equipment during the measurement.

With the following methods some of these disadvantages can be minimized. Necessary maximum height can be restricted to some predetermined ceiling. This value for communication antennas depends on far field distance and the height of the maximum ionospheric layer for communication. In other words, it depends on maximum reflection angle from the ionosphere. This is shown in Fig. 15. An example can also be given for the worst possible case:

Taking 1000 Km for long range communication at daytime, the main reflection will be at 250 - 400 Km height; this gives an angle of 26-38 degrees assuming a plane earth as shown in Fig. 15.

At 30 MHz the far field for a 20m antenna height d is:

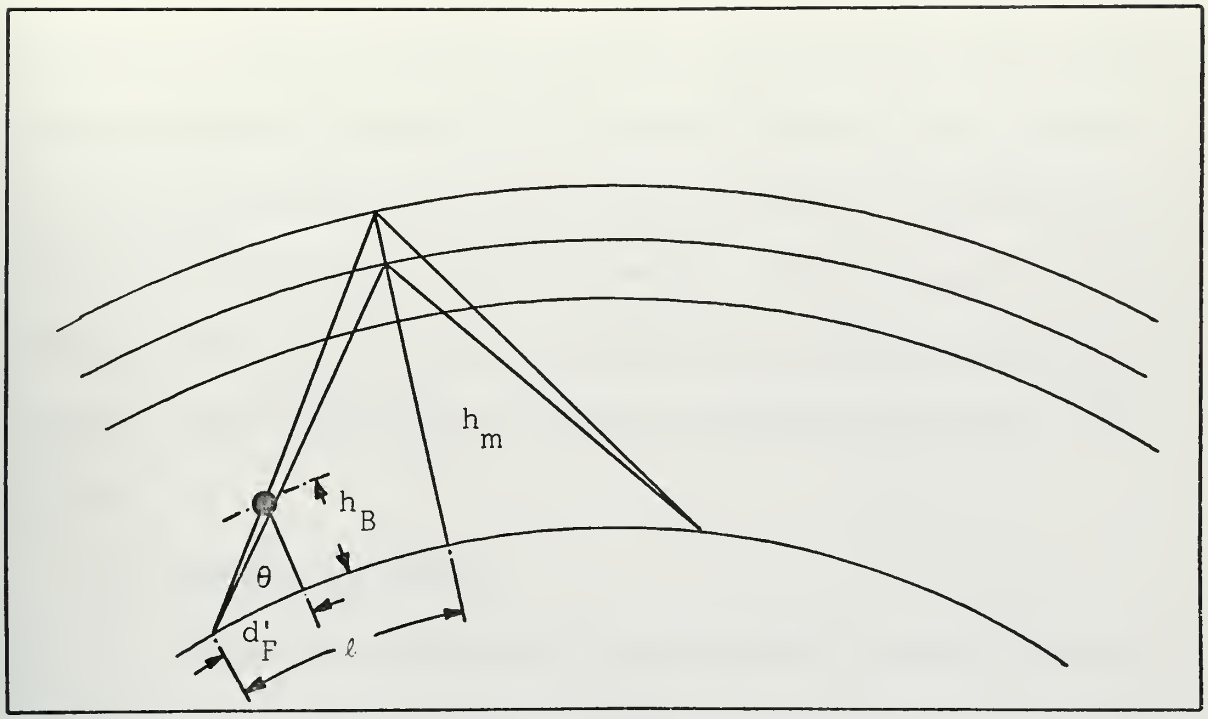
$$d_F = \frac{2d^2}{\lambda} = \frac{2 \times 400}{10} \doteq 80\,\text{m} \qquad (10)$$

Taking a 45° angle, the worst elevated position height will be:

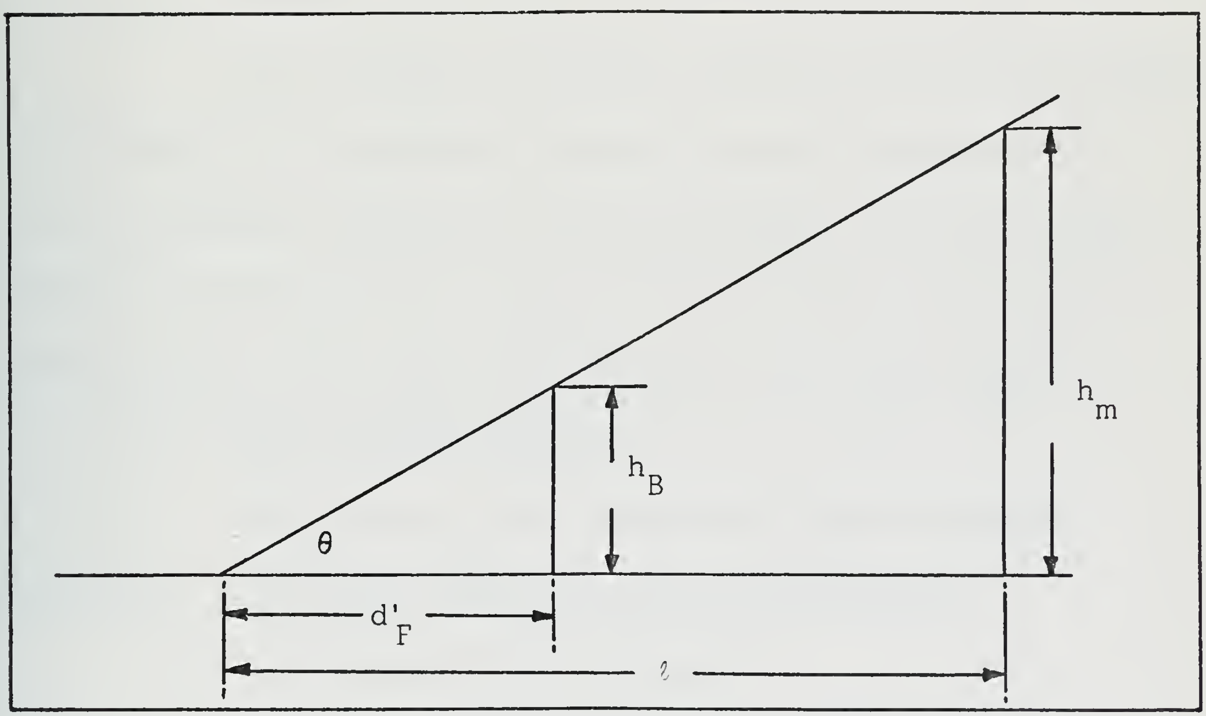
$$h_B = d_F \times \text{Sin}\ \theta = 56\,\text{m}$$

The handling of a captive balloon at 56 meters is feasible

The balloon can be controlled to a certain extent by three



Curved earth



Plane earth

Figure 15. Worst case calculation for height of balloon

guidelines. Horizontal traverse movement of the balloon will not presend a serious problem because the balloon can be tracked by optical sights, and corrections applied. The error, in field intensity, with horizontal radial movement will be considerably smaller. The only problem is the movement of the balloon in vertical position caused by wind speed and direction. Some allowance is assumed for vertical measurement, i.e., $25^{\circ} \pm 2^{\circ}$.

2. Required Equipment

The following equipment is necessary for vertical pattern measurements using a balloon platform: antenna; field intensity; telemetry transmitter.

a. Antenna

The horizontal and vertical patterns of the recording antenna on the balloon have importance in defining accuracy of measurements. First, the horizontal pattern must be omnidirectional. To keep the ship antenna in the same gain, the vertical pattern must be a secant squared pattern in order to obtain the same directivity in all vertical angles.

b. Field Intensity Receiver

This will be a small receiver with voltage controlled attenuation. It must have constant gain during measurement.

c. Telemetering Analog Information

Transmission of information from the elevated position to station will be made with a telemetry system similar to that discussed in receiver antenna measurements. Again field intensity information

will be converted to a PCM code similar to the telemetry system used before, and it will be received by the station and decoded.

For vertical measurements on shipboard receiving antennas, there will be only a transmitter in an elevated position. Other parts of the system will be the same as horizontal plane measurements. A block diagram is given in Fig. 16, for vertical plane transmitter antenna measurements.

d. Automatic Tracker

Also in this phase, a portable optical tracker can be developed for precise tracking of the recorder antenna. The easiest way is to use synchro circuits with optical tracking. In future studies this can be converted to an automatic tracker which uses telemetry signals from an elevated position.

3. Radio Direction Finder Calibrations

For this calibration an antenna on shore will transmit a signal at the frequency desired. The loop direction readings will be compared with those obtained by optical tracking of the shore antenna. This can be done by slowly turning the ship and recording both bearings simultaneously.

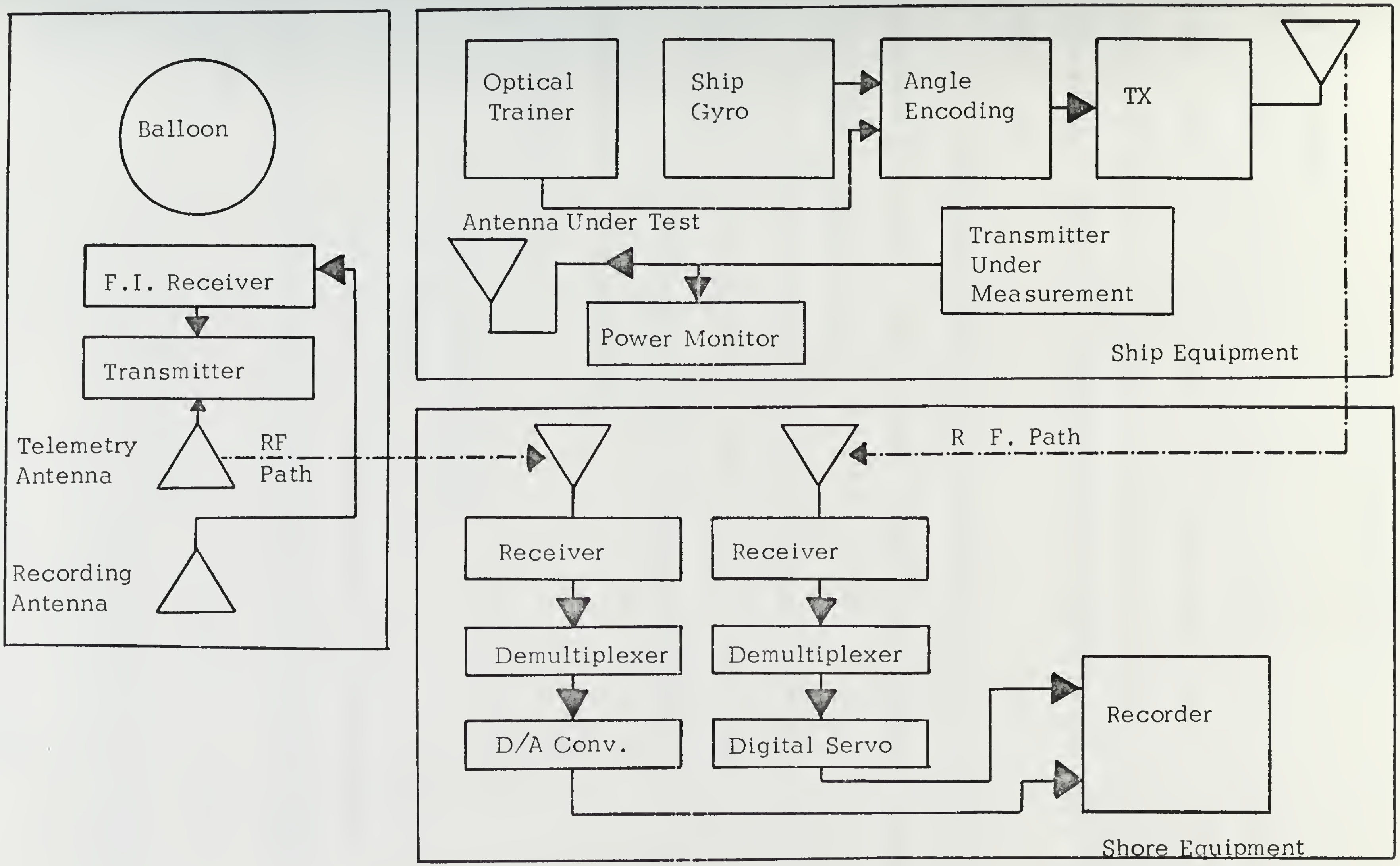


Figure 16. Setup for shipboard transmitter antenna in vertical plane pattern measurement

IV. PHASE III OF THE RANGE

A. GENERAL

Phase III measurements are cited in Chapter I. These measurements will complete the antenna range for all objectives in order to have complete measurement of any type of electromagnetic radiation device on board ship. The reasons they are only cited rather than studied in detail are:

1. The measurements are not directly related to the antenna but are preferred in a range in order to share some of the equipment available, e.g., sonar measurements.

2. The measurements give more information about the system rather than about the antenna, e.g., power spectrum, radio interference.

3. The measurements require expensive equipment, e.g., sonar measurements, countermeasures.

B. MEASUREMENTS

1. Detection and Tracking Radars

a. Power Spectrum

Power spectrum of the radars can be investigated for maximum range expectations and for performance of the complete transmitting system.

b. Range Tracking Alignment

The accuracy of range tracking information from fire control radars can be investigated.

c. Complete System Performance Measurements

Additionally, complete system performance measurements can be evaluated.

2. IFF

Antenna measurements of IFF systems can be made at a range with the same methods as used at other frequencies. System performance calibration measurements as stated in c. can also be used to include IFF systems.

3. Electronic Countermeasure Equipment

This will be required for passive equipment only. It will be necessary to have different equipment to cover various frequency ranges and modulation techniques.

4. Underwater Detection Systems

In general it will be desired to make pattern measurements of underwater transducers, power intensity calibrations and spectral examinations. In addition a capability for boresight alignment of transducers would be desired. In detail the design of the installation required for this section must be determined by the shipboard equipment in service when this range capability is planned.

5. Vertical Measurements

The balloon for vertical measurements can be replaced with a fixed tower. Towers up to 1000 feet are commercially available. The tower eliminates the errors caused by movement of the balloon. The recording antenna can be positioned by use of a carriage on a track along the tower.

V. RECORDING ANTENNA DESIGNS FOR RANGE

A. RANGE OF UHF RECORDING ANTENNA FOR RANGE

After studying several types of frequency independent antennas and design methods, Carrel's [12] method is selected for the design of a log periodic dipole antenna (LPD) for use as a UHF recording antenna. This method has been selected after extensive analysis of LPD antennas. Design procedures are given to achieve a preselected directivity, input impedance and frequency limit.

For this particular antenna, the frequency limit is selected from 225 MHz to 400 MHz to cover all military UHF communication frequencies.

The basic scheme for the antenna is given in Fig. 17, and the parameters are explained.

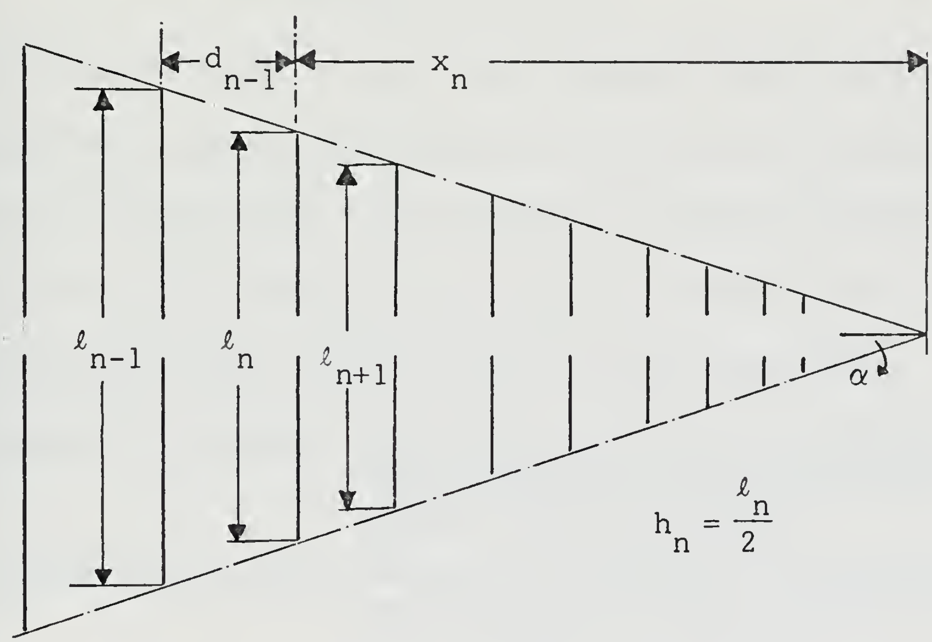


Figure 17. Dimensions for the log periodic dipole antenna

The longest element number is #1. h_n is one-half length of the n^{th} element. The other parameters are:

τ: Scale factor: ratio of successive element length which is given by

$$\tau = \frac{\ell_n}{\ell_{n-1}} = \frac{h_n}{h_{n-1}} \tag{11}$$

σ: Relative spacing: ratio of element spacing to twice element length

$$\sigma = \frac{d_n}{2 \ell_n} \tag{12}$$

α: The angle between the center axis and the line passing through end points of dipoles

The geometry of the antenna relates τ and α to σ with the following relation:

$$\sigma = \frac{1}{4} (1 - \tau) \cot \alpha \tag{13}$$

With proper selection of σ and τ and frequency limits, the antenna can be designed for desired input impedance and frequency-independent characteristics within certain frequency limits. Input impedance also depends on the ratio of element length to the cross-section area. Antenna characteristics are related qualitatively to LPD parameters below:

Increase τ (σ constant):	Decrease bandwidth of active region, increase directivity of the antenna and a small decrease in input impedance.
Increase τ (α constant):	Decrease in bandwidth of active region, small decrease on input impedance and small increase in directivity.
Increase σ (τ constant):	All parameters will increase.
Increase σ (α constant):	Bandwidth of active region increases and small decrease in directivity.

Increase Z_o: Increase of input impedance and small decrease in directivity.

These characteristics are true when LPD parameters are used within the following values:

$$0.875 < \tau < 0.98$$
$$0.05 < \sigma < \sigma_{opt}$$
$$100 < Z < 500$$
$$20 < h/a < 10000$$

With these values, directivities between 7.5 db and 12 db are obtainable.

For the design of the antenna, first σ and τ are selected for necessary directivity. Z_o is then adjusted to obtain the required input impedance R_o. One starts with an optimum σ for minimum boom length and minimum number of elements, then proceed to a lower value of σ.

For initial values of constant directivity as given by Carrel [12] and for a directivity of 10 db or 8 db, several scale factors τ and relative spacing σ are found. Then α angle is found with the following equation:

$$\alpha = \tan^{-1}\left[\frac{(1-\tau)}{4\sigma}\right] \tag{14}$$

Departure from optimum relative spacing causes increases in SWR and decreases in the front to back ratio. These are two important parameters for a recording antenna. These values are then taken as design parameters.

The second task will be to find a solution for characteristic impedance for the feeder so as to give the required input impedance R_o. The

dominant factor on the Z_o, R_o relation is the average characteristic impedance Z_a, which is governed by the ration h/a. h/a must be chosen with structural considerations, and ideally should be the same for each element. However, element diameters could be taken in groups, taking h/a = 50 as a feasible number to give the diameter of 4 mm for the shortest element and 8 mm for the longest element.

Then Z_a is:

$$Z_a = 120\ (\ell n \frac{h}{a} - 2.25)\,. \tag{15}$$

Introducing mean relative spacing,

$$\sigma' = \sigma\sqrt{\tau}\,. \tag{16}$$

With known values of σ, τ, and α, the active region bandwidth is found using the following formula:

$$B_{ar} = 1.1 + 77\ (1-\tau)^2\ \mathrm{Cot}\,\alpha \tag{17}$$

The operating bandwidth which is known is smaller than the structure bandwidth. Structure bandwidth can be obtained by:

$$B_s = B \cdot B_{ar} \tag{18}$$

where B_s = structure bandwidth

B = operational bandwidth

After B_s is found, applying B_s to the following equation, boom length is found in terms of the longest operating wavelength:

$$\frac{L}{\lambda_{max}} = \frac{1}{4}\ (1 - \frac{1}{B_s}\ \mathrm{Cot}\,\alpha) \tag{19}$$

Then using τ and B_s, the number of elements is obtainable. Choosing the average characteristic impedance for dipoles with the following equation:

$$Z_a = 120 \left(\ln \frac{h}{a} - 2.25\right) \tag{20}$$

By using the following equation, the characteristic impedance of the feeder can be found:

$$\frac{Z_o}{R_o} = \frac{1}{8\sigma' \frac{Z_a}{R_o}} + \sqrt{\frac{1}{\left(8\sigma' \frac{Z_a}{R_o}\right)^2} + 1} \tag{21}$$

After Z_o is found, the feeder can be constructed employing a two-wire transmission line equation:

$$Z_o = 120 \text{ Cos h}^{-1} \frac{b}{a} \tag{22}$$

which can be written

$$\text{Cos h}^{-1} \frac{b}{a} = \frac{Z_o}{120} \tag{23}$$

Then

$$\log \left(\frac{b + \sqrt{b^2 - a^2}}{a}\right) = \frac{Z_o}{120} \tag{24}$$

When a diameter "a" for the feeder is chosen, separation of the feed line can be found.

Only one point is left. This is the length of the longest element, which is given by:

$$h_1 = S \frac{\lambda_{max}}{4} \tag{25}$$

In the equation above, S is a shortening factor and is a function of feeder characteristic impedance and h/a ratio, [Ref. 12].

For a directivity of 8 db and 10 db, several calculations are carried out and presented in Table I. The optimum antenna is found with 8-db directivity. Other characteristics are given below:

$$\tau = 0.88$$

$$\sigma = 0.065$$

$$L/\lambda_{max} = 0.3$$

$$Z_a = 90$$

$$Z_o = 110$$

$$h_1 = 31.2$$

$$\alpha = 24.5^{\circ}$$

TABLE 1 a 225 - 400 MHz 8-db antenna for recording

τ	σ	α	B_{ar}	B_s	L/λ_{max}	N	R_{in}	h_i
0.825	0.18	12.7	2.13	3.72	0.8	8+	67	32
0.795	0.16	18.0	2.07	3.66	0.56	7-	70	32
0.78	0.138	22.0	2.00	3.50	0.44	6	75	31.7
0.80	0.12	23.0	1.81	3.7	0.4	6	84	31.3
0.84	0.104	23.5	1.55	2.71	0.38	7-	95	31.3
0.86	0.09	21.7	1.47	2.57	0.39	7+	102	31.3
0.88	0.065	24.5	1.34	2.35	0.3	8-	110	31.2

TABLE 1 b 225 - 400 MHz 12 db antenna for recording

τ	σ	α	B_{ar}	B_s	L/λ_{max}	N	R_{in}	h_1
0.916	0.171	7	1.55	2.71	1.29	12	70	32
0.925	0.15	7.25	1.45	2.54	1.2	12+	75	31.7
0.94	0.13	6.6	1.34	2.34	1.22	15-	84	31.4
0.96	0.095	5.8	1.22	2.1375	1.3	19+	102	31.3

VI. DESIGN OF A TELEMETRY SYSTEM

A. GENERAL

The design and development of a telemetry system will be studied in some detail in this chapter. As explained before, the function of this equipment will be to telemeter angle information from ship to shore and will be expandable to other telemetering needs of the range.

The main information to be transmitted will be the relative bearing of the recording antenna. This information is necessary on the shore station for plotting on a real time basis. For correct telemetering of this information, many systems exist. Pulse coded modulation has the following advantages over other systems, [Ref. 13].

1. With fixed power the performance of this system will be degraded less by noise than the performance of the commonly used analog systems. Error checking systems are only developed in digital systems. This can be done for warning or for correction to some degree; when these codes are used, rate of information flow will be less but at the same time more accurate.

2. Angle information is easily obtainable with digital encoders. Many types of available components for angle encoding have been produced for telemetry circuits.

3. The number of channels and rate of information can be changed easily. Each channel is similar to the others, and increasing the number of channels and rate of information can be achieved at relatively low cost.

4. Basic element configuration will be the same for any required

precision. A high level of precision is obtained by increasing the number of bits, thereby reducing quantization error which is, ideally, the only significant error in the system.

5. Both analog and digital information can be telemetered. This is one of the requirements for range telemetry. Any analog information can be converted to digital form and can be transmitted with this system.

6. Compatibility with digital computers for data processing can be achieved.

If a large amount of data is generated during the measurement phase, this data can be processed with the aid of a computer for automated data editing, plotting, smoothing and linearization. In a PCM system, digital data is ready at the output of the telemetry system and is easily interfaced by a digital-to-digital conversion.

B. CONFIGURATION OF THE EQUIPMENT

The basic configuration of the system is explained, by component functions, in Chapter II. This chapter has all the details for design of a PCM telemetry system. In order to avoid duplication, subparagraph D. b. of Chapter II is not repeated here.

System components which were given in Chapter II can be designed in two sections, as transmitter and receiver.

C. COMPONENTS OF THE TRANSMITTING EQUIPMENT

A detailed function diagram is given in Fig. 18.

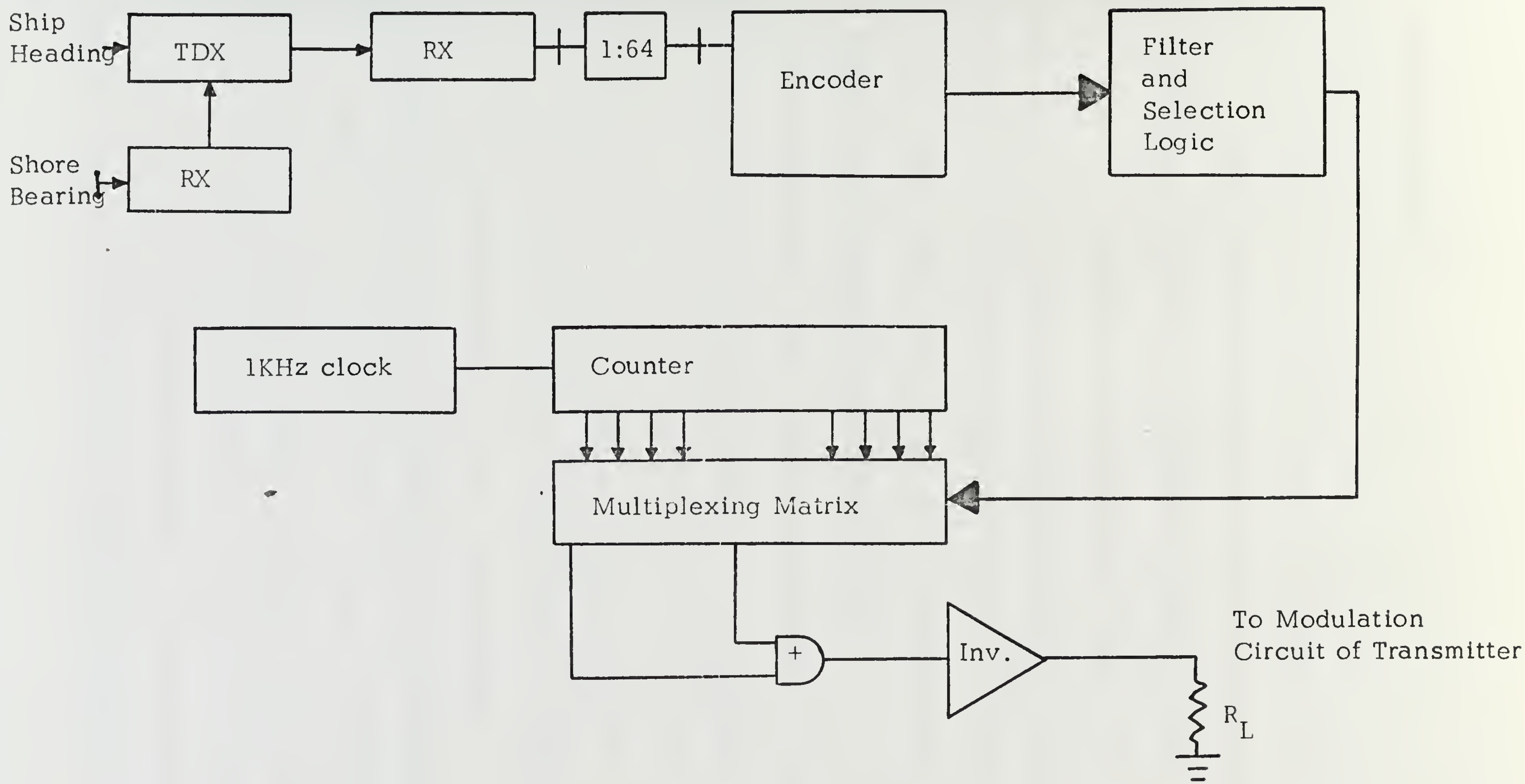


Figure 18. Block diagram of transmitter section (except transmitter)

1. Synchro Elements

Synchro elements in the beginning of the circuit are installed to obtain relative bearing of the shore station or recording antenna. The connection of a synchro differential transmitter and a synchro receiver gives the difference of the position of these two angles, which is the difference between true heading of the ship and true bearing of the ship. This is equal to relative bearing of the recording antenna or shore station. The output of RX is connected to the angle encoder with 1:64 gear ratio to have a full 13-digit count with one turn of the synchro receiver.

2. Encoder and Ambiguity Solver Selection Logic

Input to the encoder is the mechanical position of the synchro receiver, which is equal to the relative bearing of the shore station. This encoder is a 13-bit, commercial, high-precision (1/8192 of 360° or 0.0395°) device. The reason for using a high percision level is twofold:

a. To use the same bit word in transmission of analog information.

b. For future application of precise measurements.

The angle encoder output is corrected by using two brushes for each digit. Generally, encoders without such provision suffer from errors when more than one brush is aligned at a zero-to-one transition. This position can produce more than one code. To prevent this type of error, a V scan binary encoder scheme is chosen. By using double brushes and a selection logic as explained below, this kind of ambiguity can be avoided.

When a zero nonconducting area appears on any track of the

coded disk at any bit position, the next higher-order bit track has an area which does not change its state in the forward direction. This length is double the size of the first bit length. Conversely, when a one (conducting area) appears on any track, the next higher order will not change the state in a backward direction for double the size of this bit length.

Accordingly a single brush will indicate the true shaft angle (position line). Two brushes on each higher-order track, one leading the reading line and one lagging, are logically switched on and off out of circuit in order to avoid reading between code counts. This logic has the following rule: when a brush reads one, read the next higher-order lagging brush. If it reads zero, read the next higher-order leading brush. This can be written, Ref. 14:

$$B_n^{out} = \overline{B_{n-1}^{out}} \cdot B_n + B_{n-1}^{out} \cdot B'_n \qquad (26)$$

where

n = n^{th} bit; bit one is the least significant bit

B_n^{out} = n^{th} bit binary output value

B_n = n^{th} lagging brush value

B_n^1 = n^{th} leading brush value

A truth diagram for Eq. (26) is given in Fig. 19.

B_n	B'_n	B^{out}_{n-1}	$\overline{B}^{out}_{n-1}$
1	1	1	0
1	1	0	1
1	0	1	0
1	0	0	1
0	1	1	0
0	1	0	1
0	0	1	0
0	0	0	1

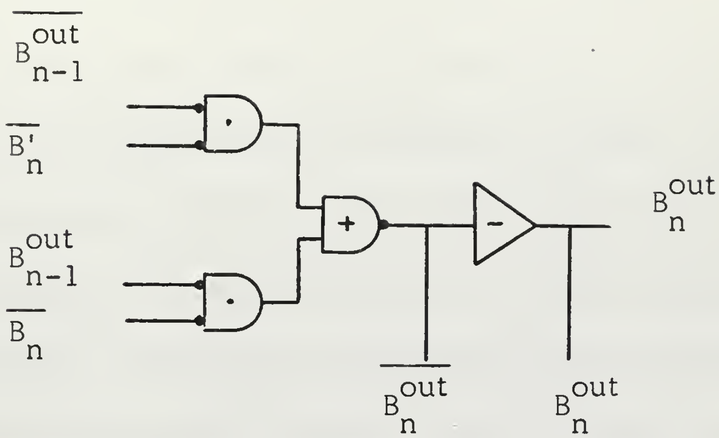


Figure 19. Ambiguity solver selection logic

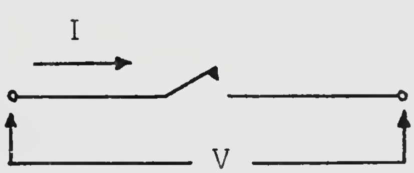
This equation also can be realized using a commercial NAND/NOR circuit in an inexpensive manner. A circuit for this equation will have the following configuration with complements of input signals[1].

The circuit shown in Fig. 19 has the following function:

$$B^{out}_n = \overline{\overline{\left(\overline{\overline{B^{out}_{n-1}}} \cdot \overline{B'_n} + \overline{B_{n-1}} \cdot \overline{\overline{B_n}}\right)}} \qquad (27)$$

which is equal to Eq. (26). The inputs to this logic are obtained from 25 brushes which are arranged in V scan logic.

This particular encoder has limits as shown in Fig. 20



$V \leq 20V$

$I \leq 2$ ma

Figure 20. Electrical limitations of encoder

[1]In this stage complements of signals are used to minimize the number of elements.

This restricts the input resistance of the next age. When a brush is conducting input to the gate, it must be in high level $V(1) \geq 0.8v.$; some value of the current must be supplied to the gate. This is 1.8 ma for Fairchild μL900 gates. When a gate is open, input to the gate is grounded. For grounding of the gate a large resistance is necessary parallel to the input resistance. For voltage limitation a series resistance is added to this combination and a small capacitor is used to form a passive filter to take care of brush noises, [Ref. 14].

Configuration of this step is shown in Fig. 21 for on and off position of the switches.

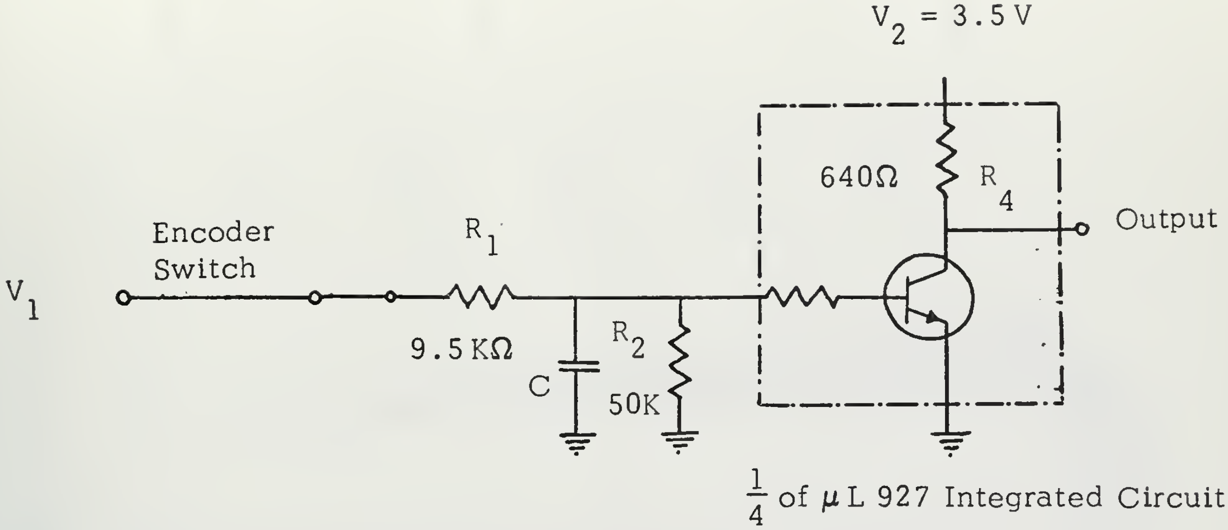
The circuitry up to this point is made for each encoder on preprinted circuit boards. The output of this section is the 13-bit parallel ones complement binary position of the encoder. The reason for the complement is to save one large element for each bit because of the NAND/NOR logic of the elements used. The schematic of the passive filter, encoder and ambiguity solver selection logic is given in Fig. 22.

Blocks shown in Fig. 22 with F_1 are passive filter circuits shown in Fig. 21. The output of this circuit is ready for a series conversion with multiplexing.

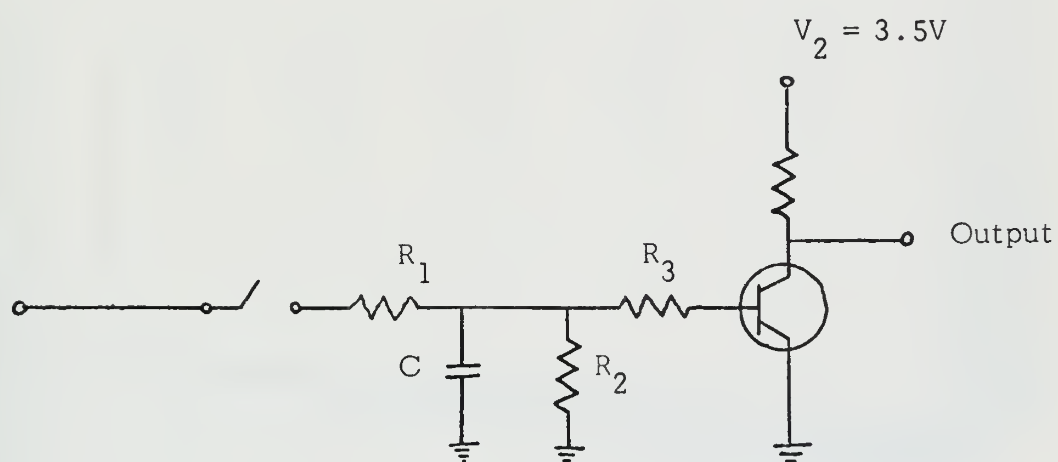
The reason multiplexing is chosen for parallel-to-series conversion instead of a shift register is the slow nature of the data rate which is limited by the bandwidth of the transmitter.

3. Clock and Multiplexer

A basic multiplexing scheme is studied for parallel-to-series



Encoder switch is closed



Encoder switch is open

Figure 21. Passive filter and first gate

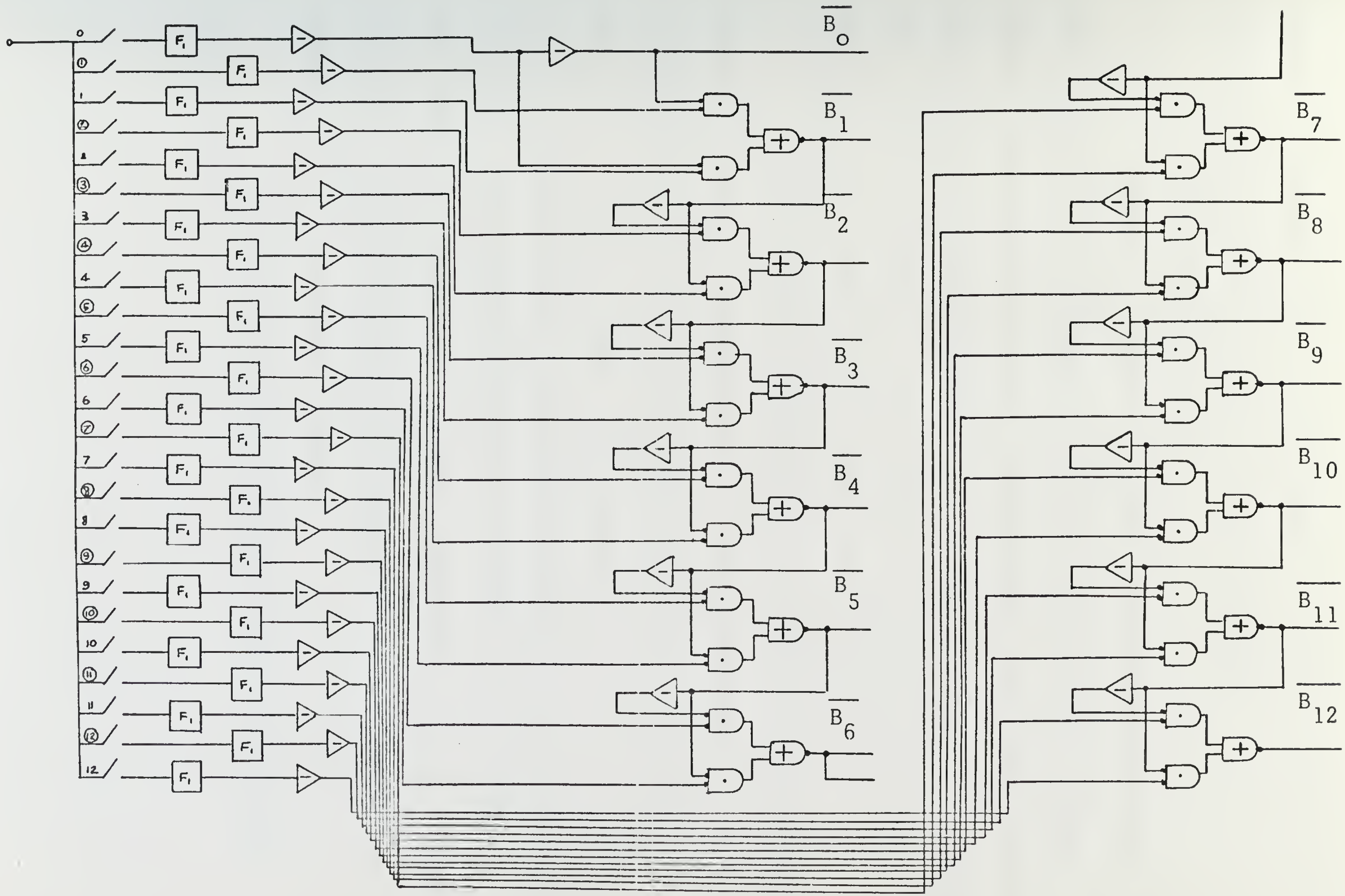


Figure 22. Schematic for encoder passive filter and selection logic

conversion of encoder output. In this paragraph, a design study for the clock counter and the multiplexer matrix are represented.

a. Bandwidth Requirements

The required bandwidth for this telemetry depends on the rate of change of angle information with the sampling theorem. When shipboard UHF equipment is used, the upper limit of bandwidth is restricted by the bandwidth of that transmitter. For all naval UHF sets this bandwidth is from 300 Hz to 3300 Hz. If the third harmonic of the sine wave is included, the highest clock rate is one KHz with 0.5 ms pulses.

This clock rate corresponds to one angle position in 16 milliseconds and roughly 64 words/second. If analog information is included for transmission, the rate of angle position goes down 8 words/second, with 0.03° resolution per word. This corresponds to 115.2° per minute. By use of a sampling theorem, ship turning speed must be less than 57.6° per minute. This is the equivalent of 6.24 minutes for one complete turn. When eight channels are introduced, this will go up to 25 minutes for one turn. When two channels out of eight are assigned for angle telemetry, this will go down 12.5 minutes.

Several values are calculated and shown for given resolutions in Table II.

TABLE II

SHIP TURNING TIMES WITH AVAILABLE BIT LENGTH

Resolution Degree	No. of Bit	Single Channel		2 of eight channel	
		Deg/Min	Period m.	Deg/Min	Period m.
0.03	13	115.2	6.24 m	28.7	25 m
0.06	12	230.4	3.12 m	57.6	12.5 m
0.12	11	460.8	94 s	115.2	6.25 m
0.24	10	921.6	47 s	230.2	3.125 m
0.48	9	1842	23 s	460.8	94 s
0.96	8	3684	11.5 s	921.6	47 s
1.92	7	7368	5.75 s	1842	23 s
4.0	6	14736	2.875s	3684	11.5 s

For clock frequencies of 1 KHz, 4KHz and 8 KHz, minimum ship turning period as a function of resolution is given in Fig. 23 . It is seen from this figure that the system is responsive with highest resolution in a practical time of 25 minutes for one turn. For radar recordings, angle resolution goes down to four degrees for 10 revolutions of the radar antenna per minute. To improve resolution for the radar system measurements, a higher clock frequency is necessary. When an eight KHz clock rate is applied, resolution is reduced to less than one degree. For initial measurements with a single channel, resolution is less than one degree for radar antennas with 10 rpm.

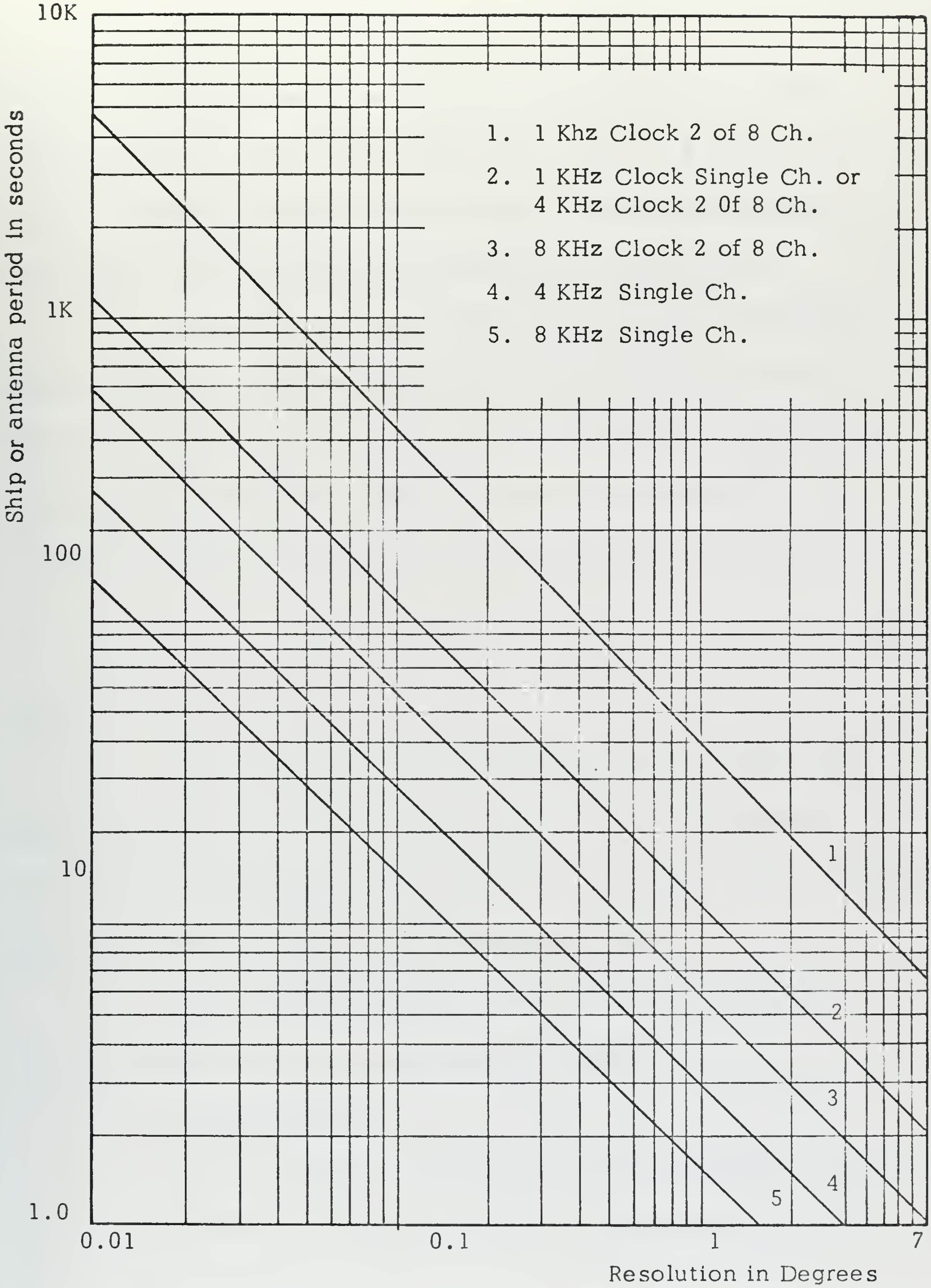


Figure 23. Ship turning time versus resolution for several values of clock

b. Design of the Clock

A square wave generator is designed for the clock with 1-KHz, 3-V peak-to-peak square wave output. This is a standard multivibrator. Diodes are used to shape the output waveform with vertical edges with the addition of two diodes and two 1-K Ω resistors.

In Fig. 24, the clock configuration is given and element values are shown, except for capacitances which govern frequency. 4-KHz and 8-KHz clocks can easily be generated from this configuration. In this type of multivibrator, clock frequency can be adjusted by using the following formula when $R_1 = R_2$, $C_1 = C_2$ for symmetric operation:

$$T = 2 R_1 C_1 \ln\left(1 + \frac{V_{CC}}{V_{BB}}\right) \tag{28}$$

where

T is the period of one cycle for square wave output. For proper operation, $V_{CC} = 6.0V$. Taking $V_{BB} = 3.5V$, the logarithmic part of the formula became equal to one. R_1 is 1×10^4 ohms. For a 1-ms period, that is for 1-KHz operation, C_1 is found to be 0.05 μf.

Other clock frequencies can be changed by changing C_1 and C_2; small adjustments can be made by adjusting V_{BB}.

c. Counter Circuit

For generation of sequences, four Fairchild μL923 flip flops are used. These four JK flip flops generate 16 sequences which can be recognized by AND gates.

Each flip flop has the truth diagram in Fig. 25.

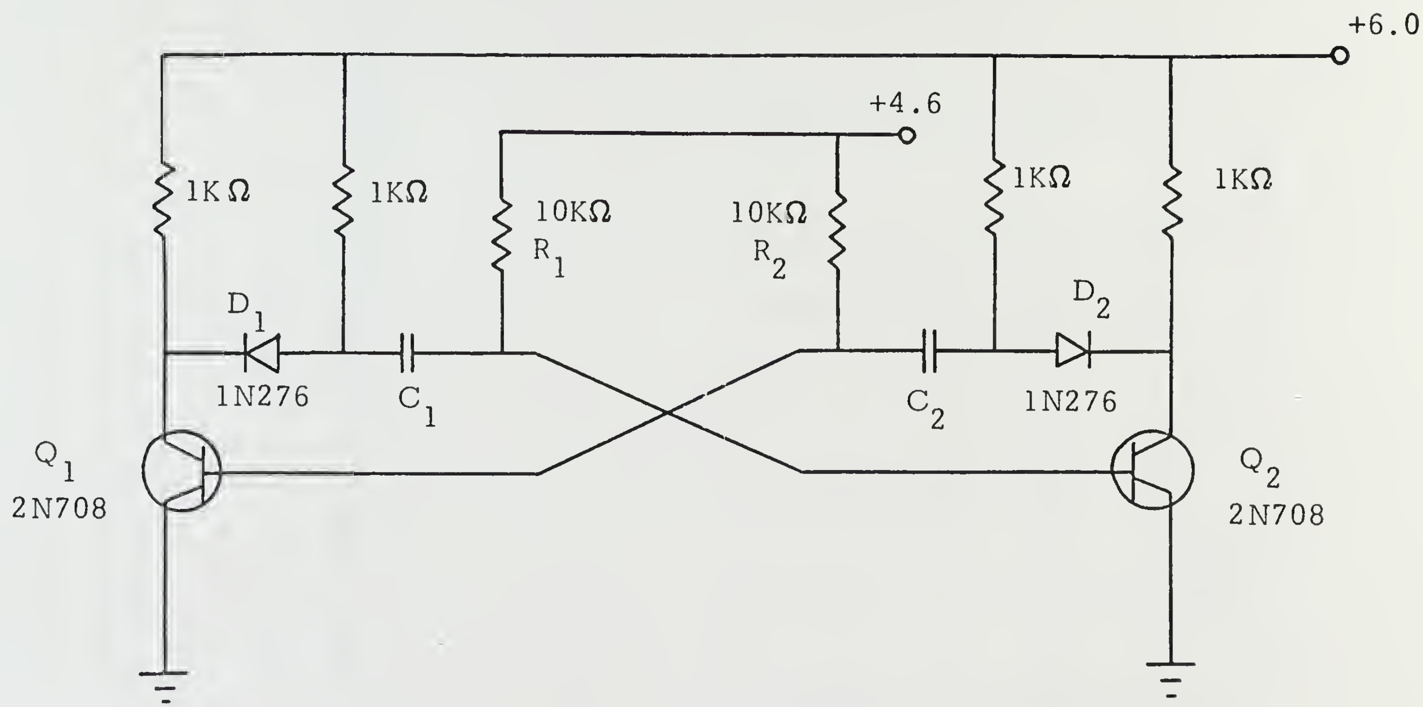


Figure 24. 1 KHz clock for transmitting equipment

Set t = n	Clear t = n	Output t = n+1
H	H	X^n
H	L	H
L	H	L
L	L	$\overline{X}^n$

Figure 25. Fairchild μL923 flip flop truth diagram

This flip flop cannot be triggered by inputs on the terminals, set #1, and clear #3. These terminals act only as conditioning inputs. The flip flop is triggered only by a falling transient on terminal #2. Therefore, as shown in the truth diagram, when #1 and #3 are high there is no effect on the output. If #1 is high and #3 is low, the transient will leave the output at the high state . If #1 is low and #3 is high, the falling transient will leave the output terminal at low state. When #1 and #3 are both low, the state of the flip flop will be reversed every time a falling transient occurs on terminal #2. Terminal #6 is a preset terminal. A high level on this terminal will set the flip flop to the state in which the output terminal #7 is low.

These flip flop counters, codes, and waveforms generated are shown in Fig. 26. The only disadvantage of this configuration is propagation time; it is negligible however with low clock rate.

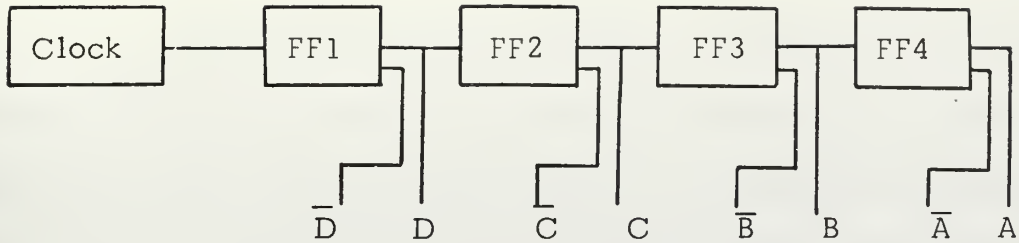
For sampling of each bit in an elementary manner, four sequence pulses, clock pulse (to generate RZ code)[1], and signal are to be sampled. For example:

$$F = A \cdot B \cdot C \cdot D \cdot S \cdot CL \tag{29}$$

where S : Signal

CL: Clock

[1]The return-to-zero method of representing data where a one is indicated by a change of envelope to the one level for 1/2 of the bit interval after which the signal returns to the reference for the remaining half of the bit interval, and a zero is indicated by no change in the signal, Ref. [13].



A	B	C	D	Sq
0	0	0	0	1
0	0	0	1	2
0	0	1	0	3
0	0	1	1	4
0	1	0	0	5
0	1	0	1	6
0	1	1	0	7
0	1	1	1	8
1	0	0	0	9
1	0	0	1	10
1	0	1	0	11
1	0	1	1	12
1	1	0	0	13
1	1	0	1	14
1	1	1	0	15
1	1	1	1	16

Sq. Sequence

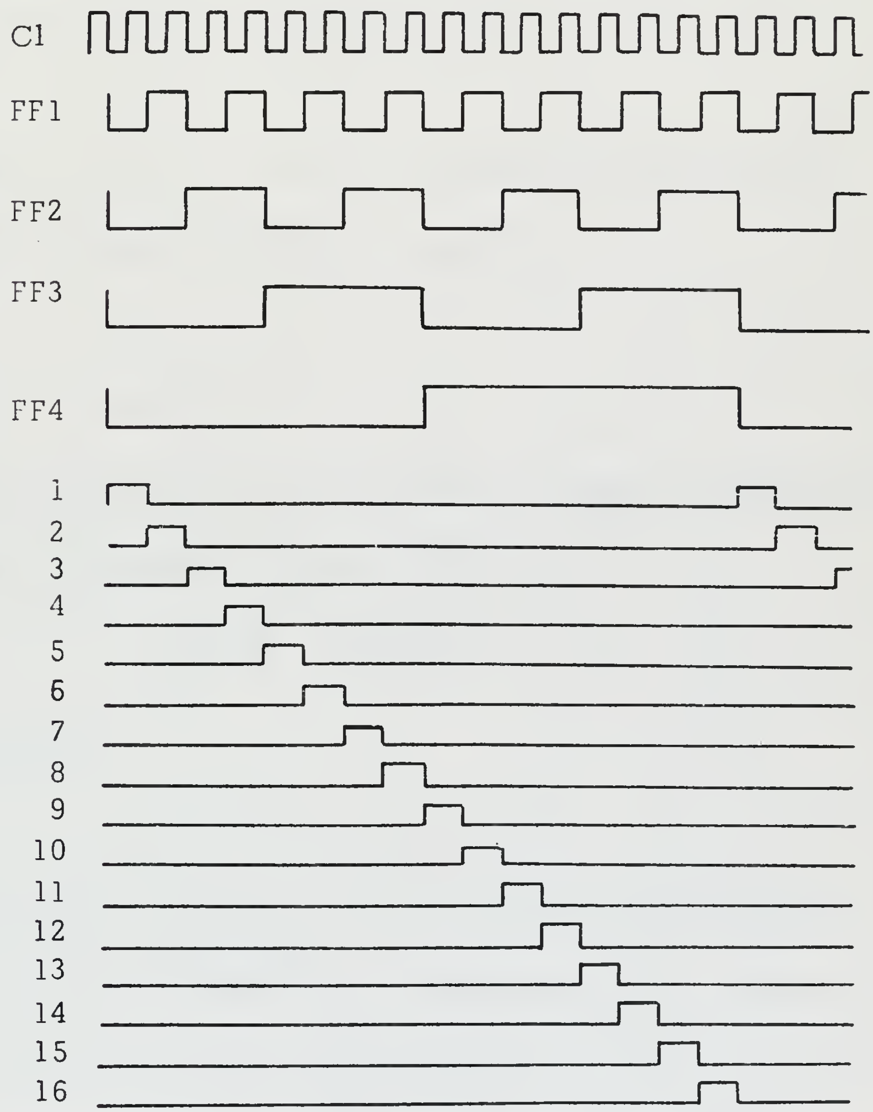


Figure 26. Multiplexer counter and generated sequences

Instead of using six input gates, to minimize the number of elements, functions $A \cdot B$ and $C \cdot D$ will be generated first. These two values, signal and clock will then be fed to a 4-input gate. Functions for $A \cdot B$ and $C \cdot D$ must be generated separately; this is done with available two-input gates.

This circuitry is used to generate 13 bits serially, with a two-bit-long frame pulse as given in Fig. 27.

As shown in Fig. 27, in order to generate bit position one in sequence four, signals one and eight are generated.

$$1 = A \cdot B$$

$$8 = \bar{\bar{C}} \cdot \bar{\bar{D}}$$

These two signals and the complement of signal and clock, are fed to No. 1 four-input NAND gate. Output of this gate, F:

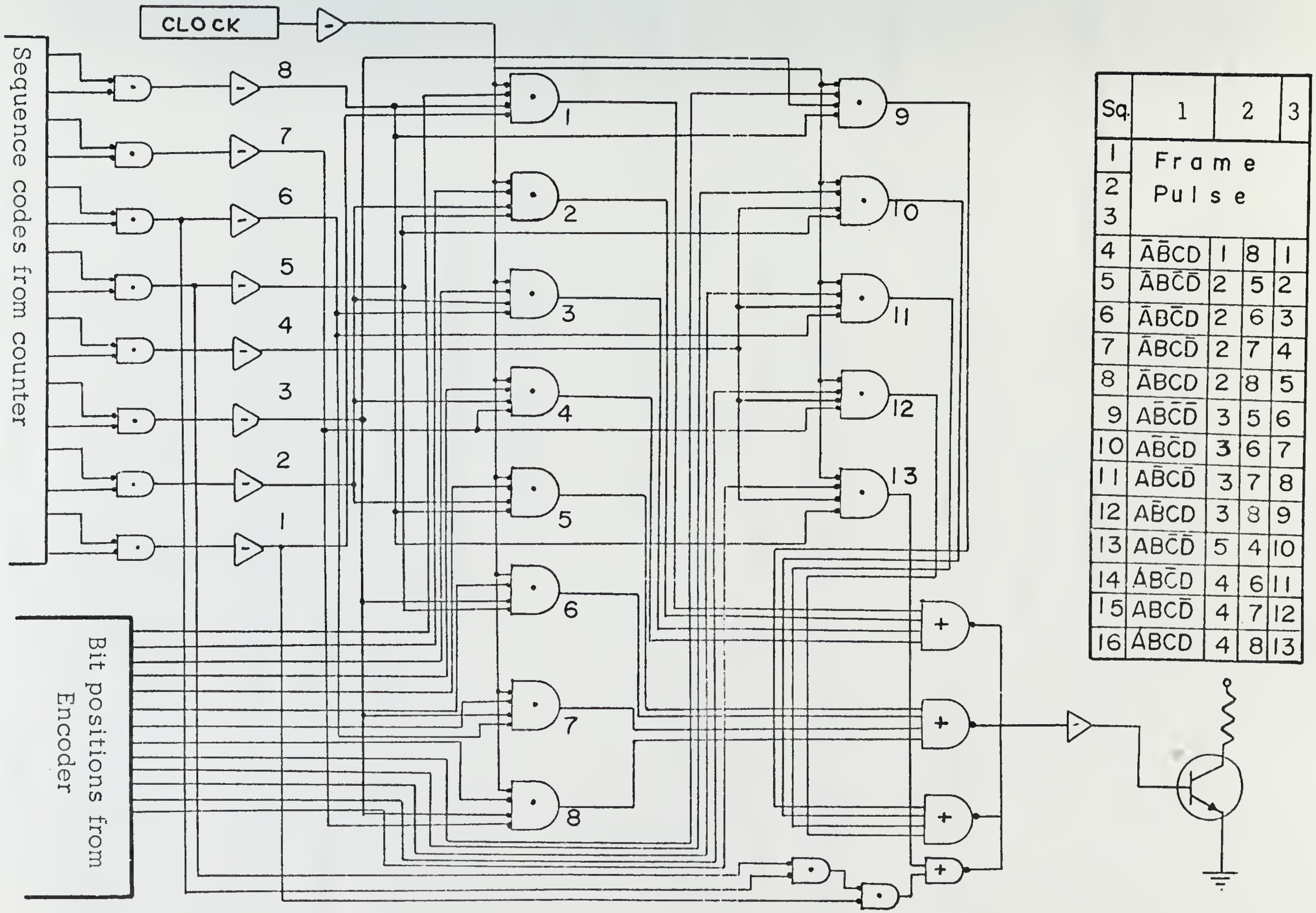
$$F = \overline{\overline{(\bar{A} \cdot \bar{B})}} \cdot \overline{\overline{(\bar{\bar{C}} \cdot \bar{\bar{D}})}} \cdot \bar{\bar{S}} \cdot \bar{\bar{C\ell}} \qquad (30)$$

which can be simplified to:

$$F = \bar{A} \cdot \bar{B} \cdot C \cdot D \cdot S \cdot C\ell \qquad (31)$$

F has the value of one at the second half of the clock cycle at sequence 3. All sequences are generated in a similar way, employing proper sequences. The only difference is the frame signal at sequence two and three, which is generated with the following logic: $\bar{7}$ and $\bar{6}$, which are $\bar{C}D$ and $C\bar{D}$, are fed to a NAND gate · output:

$$\overline{\bar{C}D} \cdot \overline{C\bar{D}}$$



Sq.	1	2	3
1	Frame Pulse		
2			
3			
4	$\bar{A}\bar{B}CD$	1	8	1
5	$\bar{A}B\bar{C}\bar{D}$	2	5	2
6	$\bar{A}B\bar{C}D$	2	6	3
7	$\bar{A}BC\bar{D}$	2	7	4
8	$\bar{A}BCD$	2	8	5
9	$A\bar{B}\bar{C}\bar{D}$	3	5	6
10	$A\bar{B}\bar{C}D$	3	6	7
11	$A\bar{B}C\bar{D}$	3	7	8
12	$A\bar{B}CD$	3	8	9
13	$AB\bar{C}\bar{D}$	5	4	10
14	$AB\bar{C}D$	4	6	11
15	$ABC\bar{D}$	4	7	12
16	$ABCD$	4	8	13

Figure 27. Multiplexing matrix (1. Sequence codes; 2. Outputs used; 3. Bit number

This output and #1 (which is $\overline{\overline{\overline{A} \cdot \overline{B}}}$) are fed to another NAND gate. This gives an output, G:

$$G = \overline{\overline{\overline{A}\,\overline{B}}} \cdot (\overline{\overline{\overline{C}D} \cdot \overline{C\overline{D}}})$$

By Demorgan theorem:

$$G = \overline{\overline{\overline{A} \cdot \overline{B}}} \cdot (\overline{\overline{\overline{C}D}} + \overline{\overline{C\overline{D}}})$$

which can be written

$$G = \bar{A}\bar{B}\bar{C}\bar{D} + \bar{A}\bar{B}C\bar{D} \qquad (32)$$

Then G will be high whenever one of the second or third sequences is high.

This frame signal will be added to the other 13 bit positions, with a combined 14-input NOR gate. Output of this will feed to an inverter buffer amplifier, and gain of this amplifier is adjusted to drive a TED transmitter, voice modulation circuit, which has an 600-Ω input resistance.

d. Seven-Channel Multiplexing

For this task another multiplexing sequence will be generated by using the output of the last flip flop. Analog to digital converters will be used with parallel outputs. Therefore, one multiplexer can be used to generate series pulses for each channel as shown in Fig. 28.

(1) Counter. This counter will have three flip flops in the same configuration as before. It will generate sequence for eight channels. For flexible channel selection, these sequence signals will

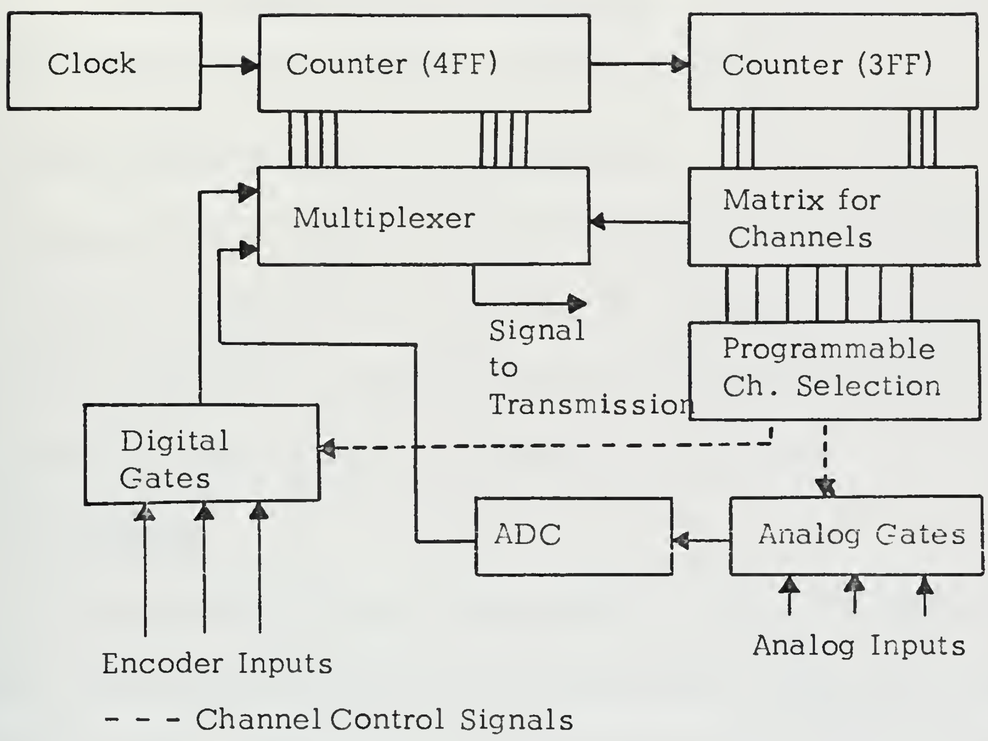


Figure 28. Seven channel multiplexing

be kept on a terminal. The first sequence will be a code for channel synchronization. The other seven sequences can be used for any analog or digital data channel. Configuration of this component is given in Fig. 29.

(2) Analog to Digital Converter. A continuous counter type analog to digital converter will be used for conversion.

D. COMPONENTS OF RECEIVING EQUIPMENT

The receiving equipment and function of components are studied in block diagrams in Chapter II. In this section, design of receiving equipment will be introduced in detail as was done in the transmitting section. A more detailed block diagram is illustrated in Fig. 30.

1. Receiver

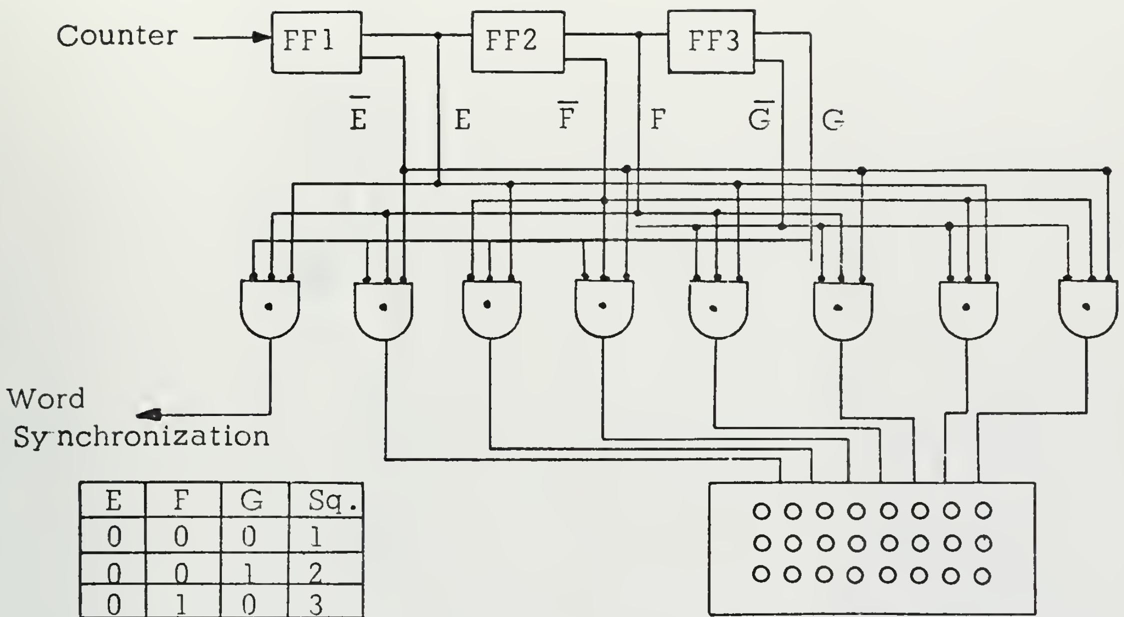
The receiver will be a Navy AN/URR 13,225 - 400 MHz UHF receiver. The signal coming from the transmitter is demodulated with a bandwidth of 300 - 330 Hz. For a one-KHz clock, the output will have only up to the third harmonic. For better response of logic circuits, this signal must be conditioned.

2. Signal Conditioning

The signal from a regular receiver will be conditioned to a certain degree. This signal has a bandwidth of 300 - 3300 Hz. Therefore, long pulses will be degraded, i. e., frame pulse. To avoid this situation, the signal will be amplified and clipped by the circuit shown in Fig. 31.

3. Bit Synchronization

To recover information from the reconditioned signal, the trailing



E	F	G	Sq.
0	0	0	1
0	0	1	2
0	1	0	3
0	1	1	4
1	0	0	5
1	0	1	6
1	1	0	7
1	1	1	8

Figure 29. Counter for seven-channel multiplexing

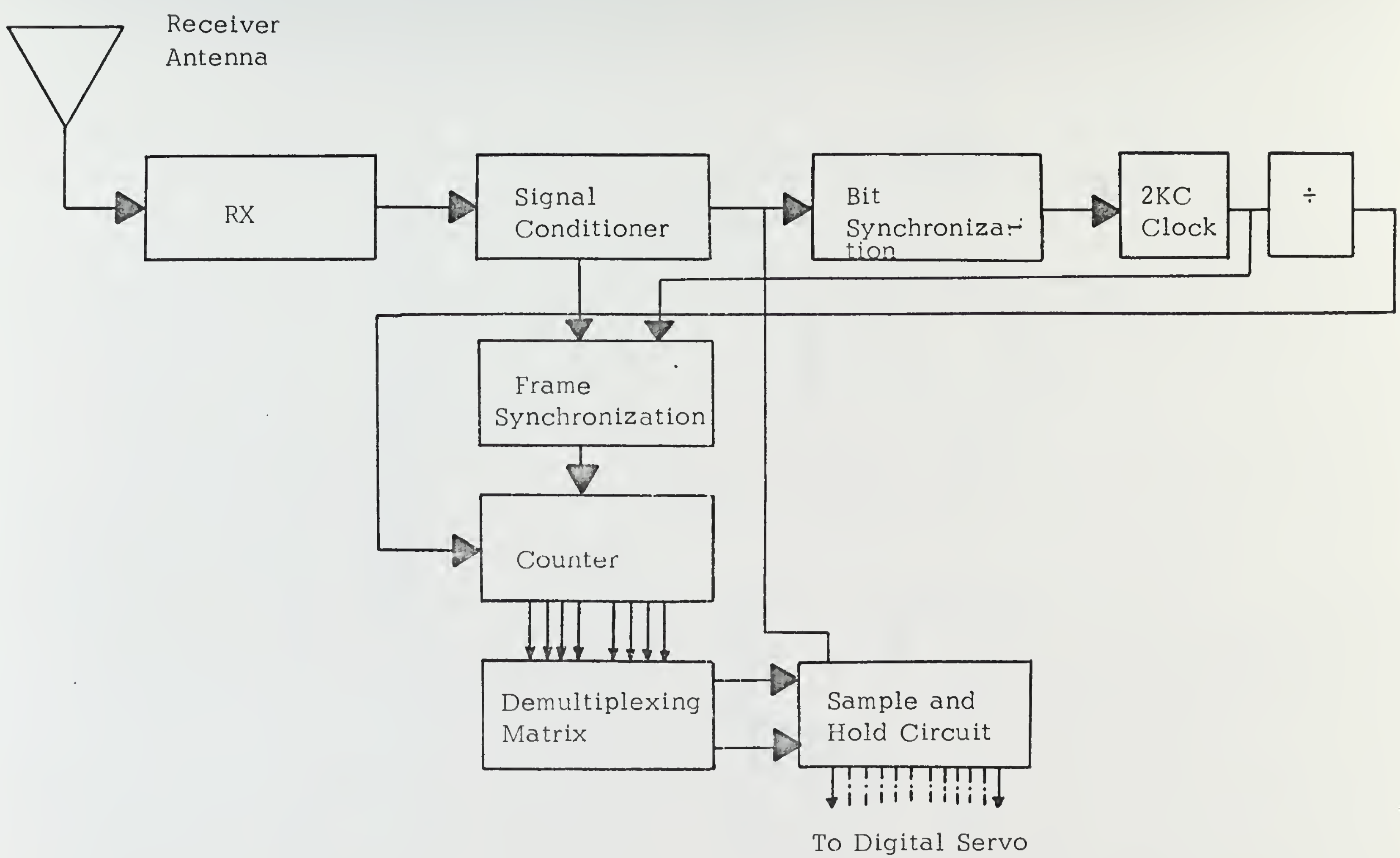


Figure 30. Telemetry receiving circuit

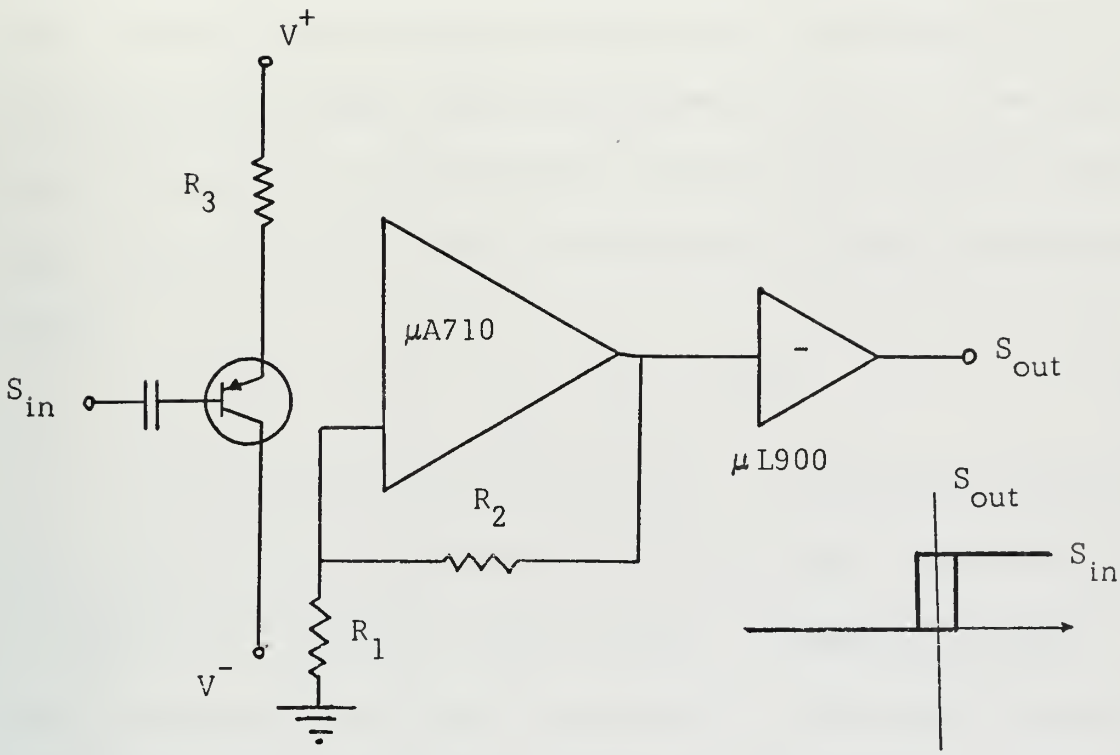


Figure 31. Signal conditioning

edges of the conditioned signal are used for synchronization. The transmitter clock is also used in the receiver, with the addition of synchronization circuitry. For differentiation of the incoming signal, a Fairchild μA9941 wideband integrated circuit will be used. The negative part of the output will be clipped with the diode shown in Fig. 32. Then with each rising pulse, Q_1 will be driven to saturation; this will give a high output at Q_2 of the clock. Output of the μA741 is shown in the following formula:

$$E_{out} = -R_2 C_1 \frac{dE_{in}}{dt} \tag{33}$$

Before deciding on values for R_2C_1, it is necessary to look at the synchronization of the clock. For synchronization, these pulses may be applied to the collector, base or emitter. For example, positive pulses are applied to the base or collector of Q_1 and negative pulses to the emitter. These triggers may produce synchronization by establishing the exact instant at which Q_1 comes out of the cutoff; this represents a high level at Q_2 output (cutoff).

To obtain positive pulses, the trailing edges of the signals are used. Negative pulses which are coming from the differentiation of the rising edges will be clipped with a parallel diode; an IN 276 switching diode is suitable.

The remaining waveform will be used to synchronize the colck and to control the state of the dividing flip flop. If this state is not controlled, 1-KHz output can have a 180^o phase difference, which is

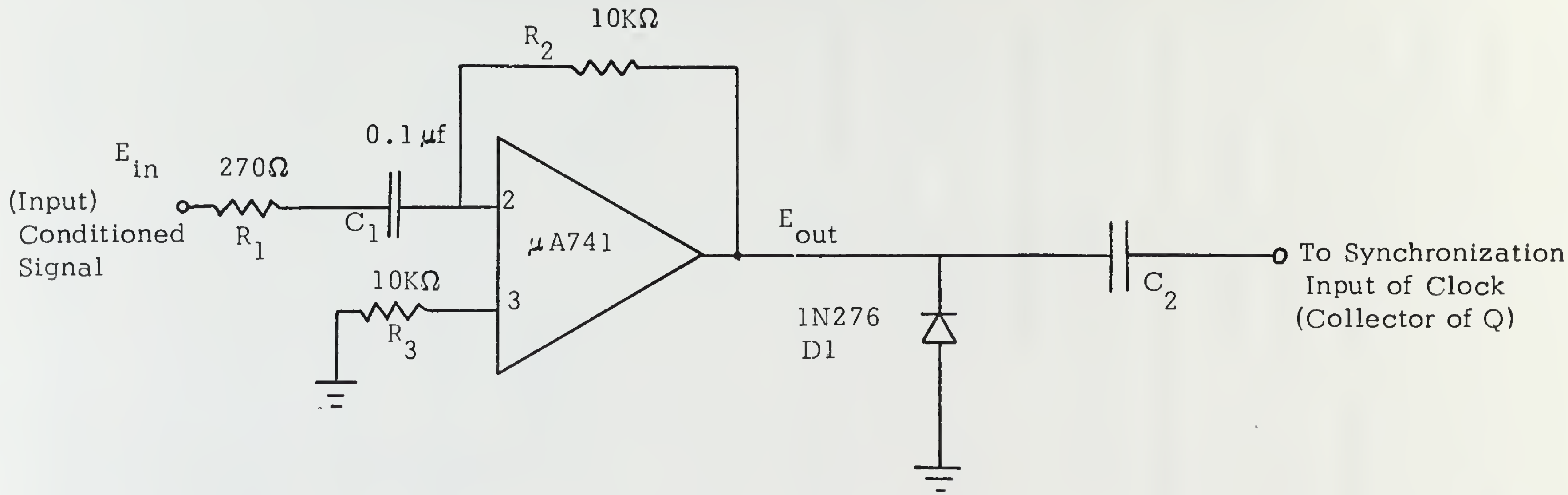


Figure 32. Bit synchronization circuit

uncontrollable. Therefore, this synchronization pulse will be applied to the collector of Q_1 and pin #7 of the dividing flip flop.

4. Clock

The clock has the same configuration as shown in Fig. 24. The only change will be the RC constant. From formula (28), again using $R = 10^4\ \Omega$, C must be 0.025 μf.

The reason for using a 2-KHz clock instead of 1-KHz is that it is necessary for the sampling hold circuit. This will be explained later.

5. Frame Synchronization

For frame synchronization, we have a two ms pulse, a one KHz clock and a Fairchild μL923 JK flip flop. A 0.5-ms pulse is generated to give the same trailing edge with frame pulse. The circuit is given in Fig. 33.

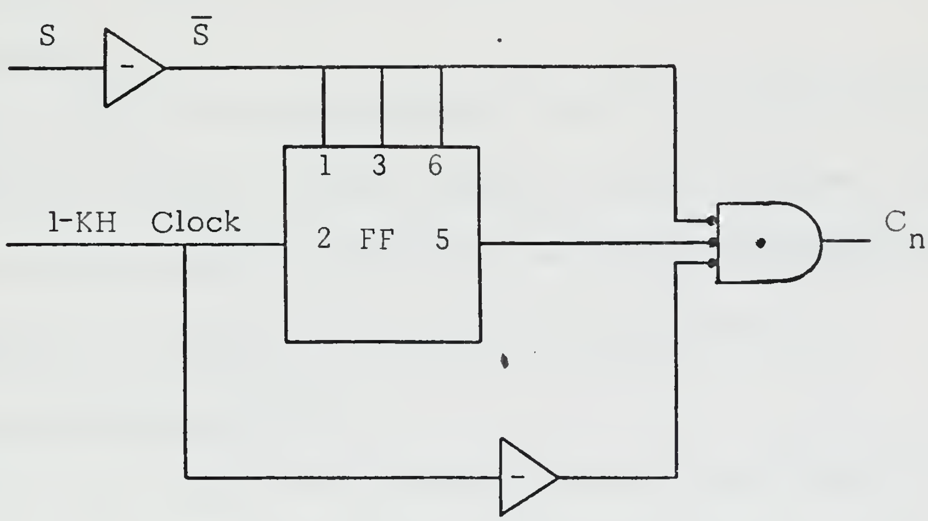


Figure 33. Generation of frame referance pulse

This flip flop can only change its state when pins one and three are low and a falling transient is observed on pin two. The flip flop does not change its state when pins one and three are high. It can only count during frame pulses and can change its state only once. These waveforms are shown in Fig. 34. Every time a return to zero occurs in the signal, pin 6 will preset the output to the low state. Proper recognition pulse of the frame can then be obtained from a three input NAND gate.

The reference pulse obtained is shown in Fig. 34. This occurs whenever output #7 of the flip flop is high, the clock is high, and the signal is high. As explained above, the only possible time this can take place is the last 0.5ms of the frame pulse.

This pulse will be used to preset counter flip flops to the low state, causing it to begin to count from the 0000 state.

6. Counter

The counter for the demultiplexing circuit is similar to the one in the transmitter section. The only sequences which are different from the previous ones are those caused by the delay introduced with frame pulse recognition. This part of the circuit is shown in Fig. 35.

7. Demultiplexing Matrix

This logic circuit is similar to the previous one in the transmitting circuit. The generated codes of the demultiplexer are shown in Fig. 36 with numbers 1 through 16. These codes will be generated using counter outputs.

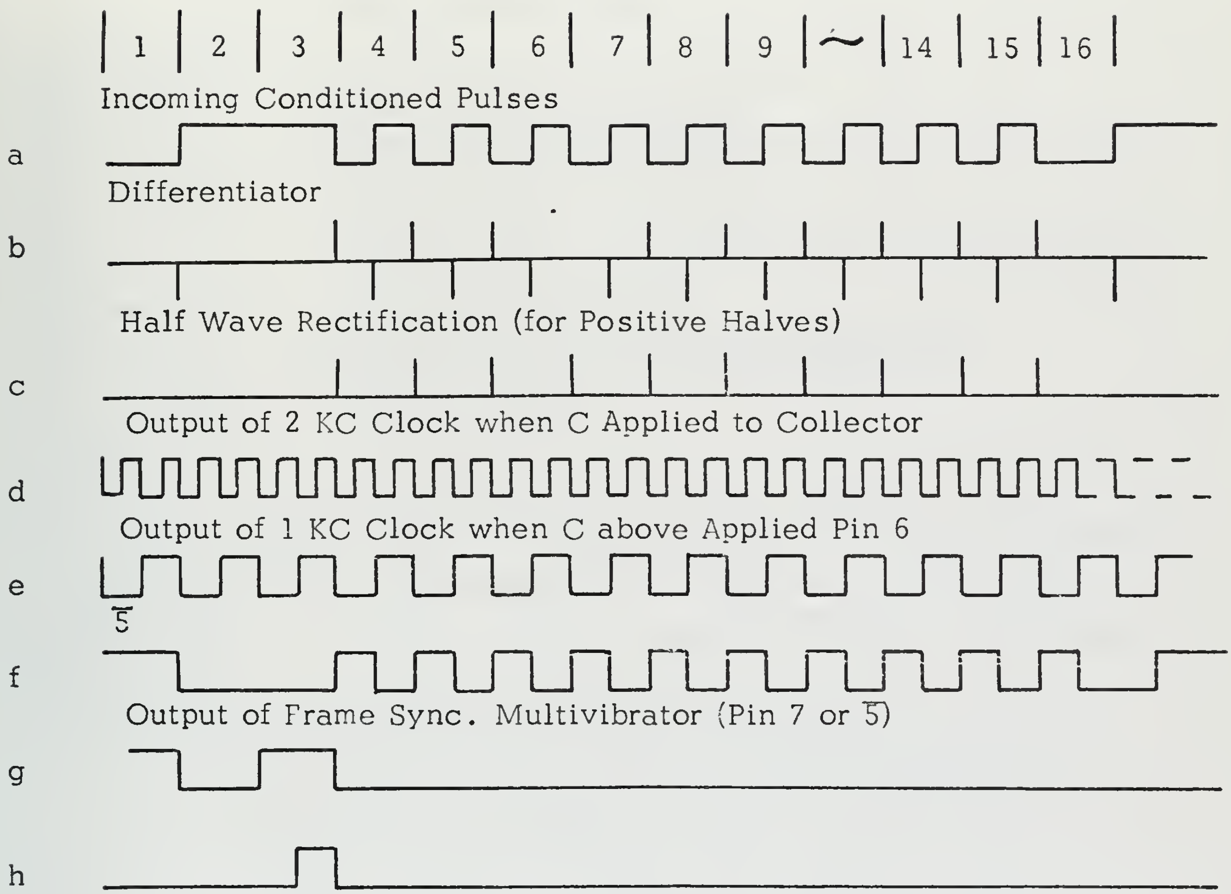
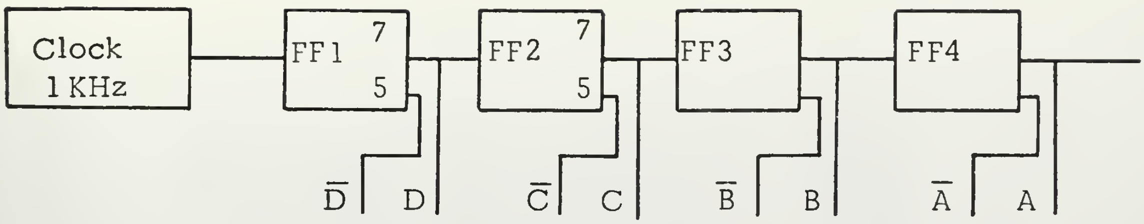


Figure 34. Receiver waveforms for frame synchronization



A	B	C	D	Sq
0	0	0	0	3
0	0	0	1	4
0	0	1	0	5
0	0	1	1	6
0	1	0	0	7
0	1	0	1	8
0	1	1	0	9
0	1	1	1	10
1	0	1	1	11
1	0	0	1	12
1	0	1	0	13
1	0	1	1	14
1	1	0	0	15
1	1	0	1	16
1	1	1	0	1
1	1	1	1	2

Sq. (Sequences)

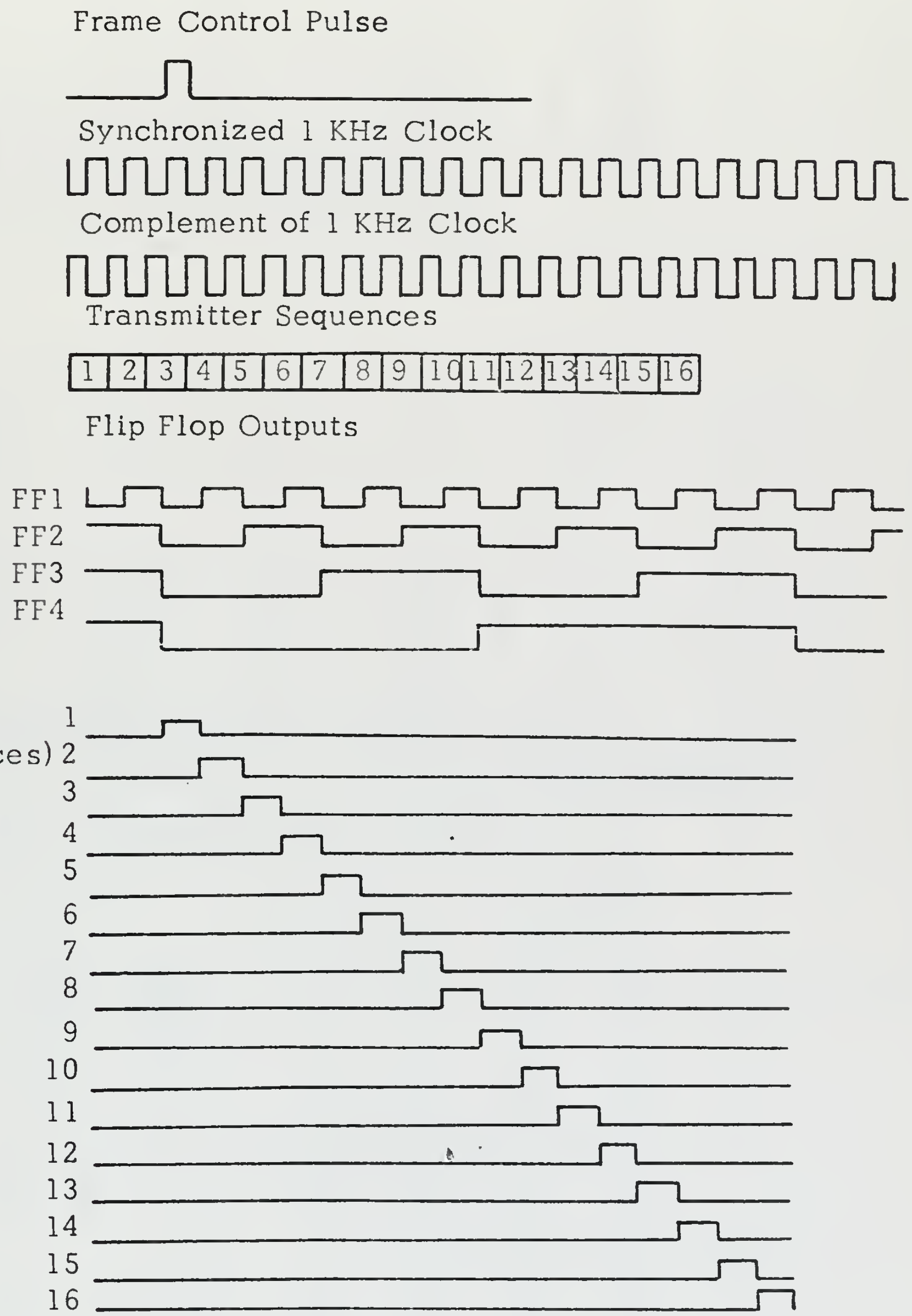
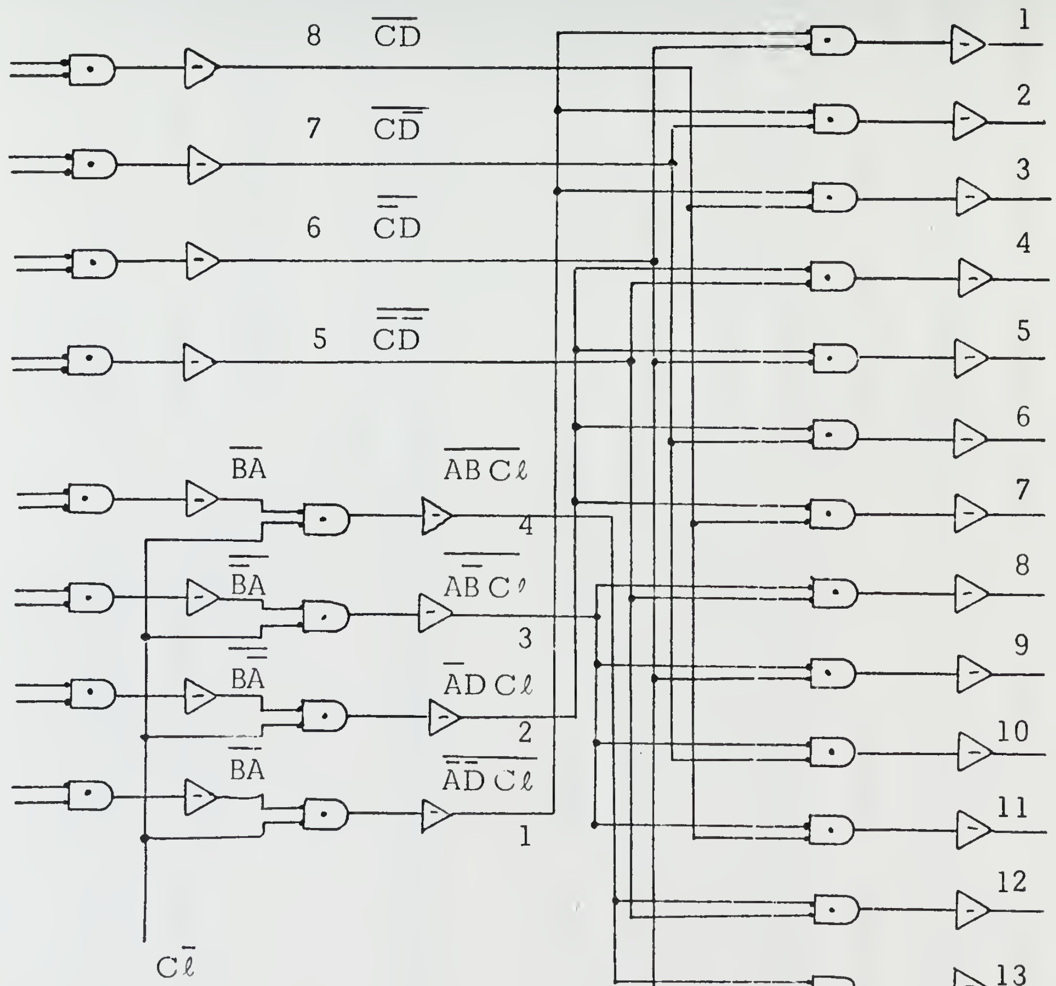


Figure 35. Receiver counter and sequence codes



Bit	1	2		Count
1	ABCD	1	6	0001
2	ABCD	1	7	0010
3	ABCD	1	8	0011
4	ABCD	2	5	0100
5	ABCD	2	6	0101
6	ABCD	2	7	0110
7	ABCD	2	8	0111
8	ABCD	3	5	1000
9	ABCD	3	6	1001
10	ABCD	3	7	1010
11	ABCD	3	5	1011
12	AMCD	4	5	1100
13	AMPD	4	6	1101

1. Necessary function
2. Parts of the function generated by gates

Figure 36. Demultiplexer matrix

8. Sample-and Hold Circuit

In the last three paragraphs, the purpose has been to translate the series pulse train to parallel form. After translation, each bit must be kept at sampling level until the next sampling. A continuous output is thereby obtained in parallel form. This will be used in digital servo equipment for comparison.

When the signal is one and the complement of the signal is zero, these two can be fed to #1 and #3 pins of a flip flop. Then a transient on pin #2 leaves the output as the high state. Conversely, if the signal is zero and the complement is one, the transient leaves the output at the low state. The transients which are obtained from the 2-KHz clock are periodically occuring; effects of the undesired transient can be prevented when the complement of the sampling signal is fed to pins one and three and an AND circuit to S and $\overline{S}$. At all other times, when the sampling signal is zero the flip flop will not be affected. These waveforms are shown in Fig. 37.

The output of bit position and its complement can then be obtained from pins #7 and #5 respectively.

E. DIGITAL SERVO SYSTEM

The output of the circuitry up to this point is 13-bit parallel continuous binary angle information. This information and its binary complement are available and can be used in a digital servo system. This signal will be compared with the signal generated from the position of the

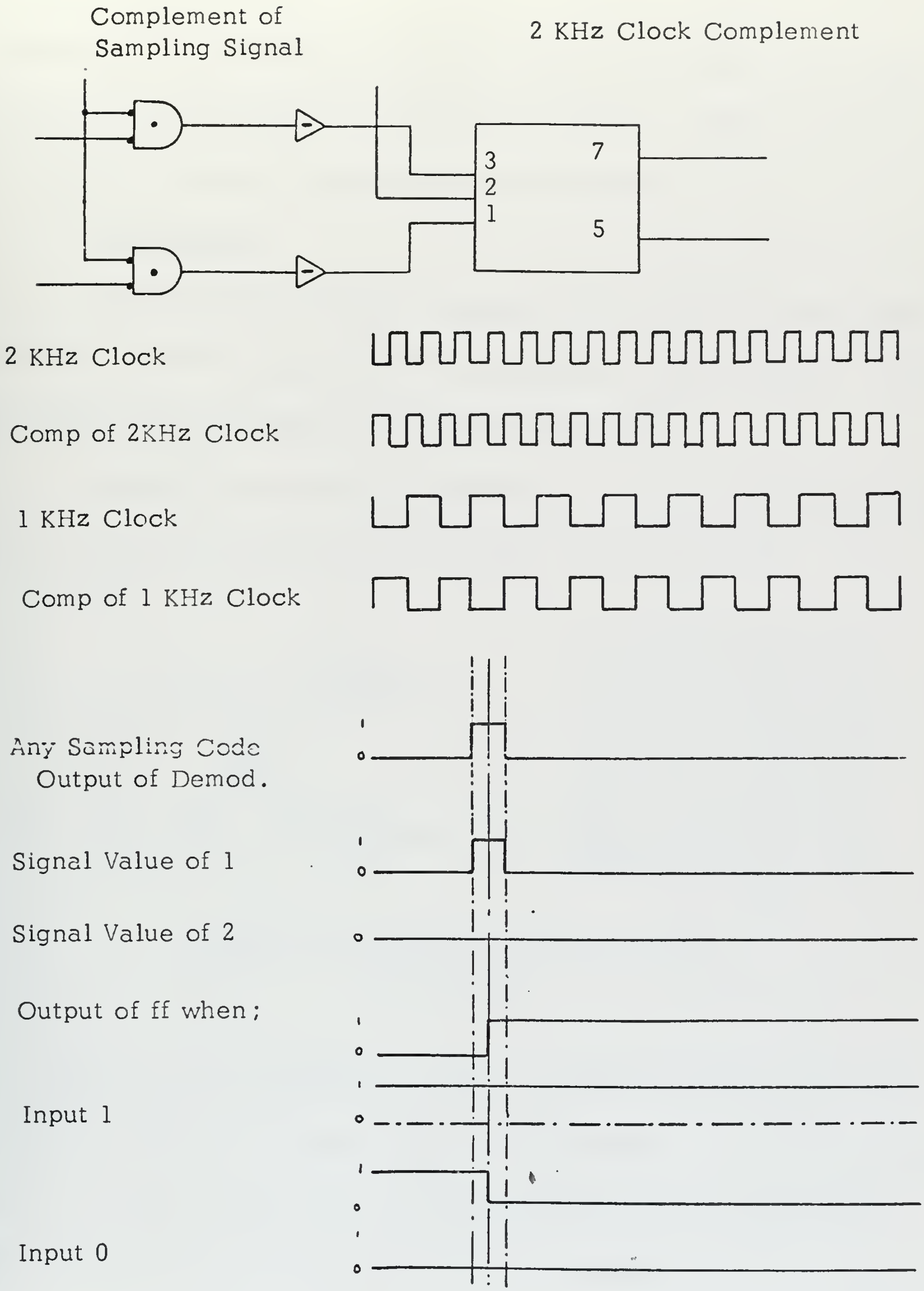


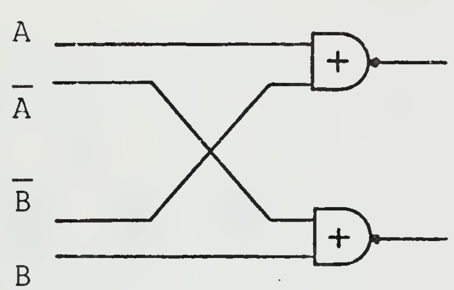
Figure 37. Sample-and-hold circuit

servo motor, and resultant binary error signal will be used to drive the servo motor to the correct position of the recorder. A more detailed circuit diagram is given for this component in Fig. 39 .

1. Comparator

In comparison of binary positions, complements of both signals are used. The reason for this is the utilization of NAND circuits. Original signals are also used for element minimization.

One NOR circuit will be enough for comparison of each bit. One of these circuits is given in Fig. 38 with a truth diagram, [Ref. 15].



A	B	$\bar{A}$	$\bar{B}$	C	0
1	1	0	0	0	0
1	0	0	1	0	1
0	1	1	0	1	0
0	0	1	1	0	0

Figure 38. Comparison for one bit and truth diagram

As is shown in the truth diagram, when A is higher than B, output D will be high, and when B is higher than A, C will be high. If A is bit position for the incoming signal, and B is bit position for the servo motor, all high outputs can be weighted with a digital to analog converter for bit significance. The error and its sign can thus be obtained.

A complete circuit will be given with the D/A converters.

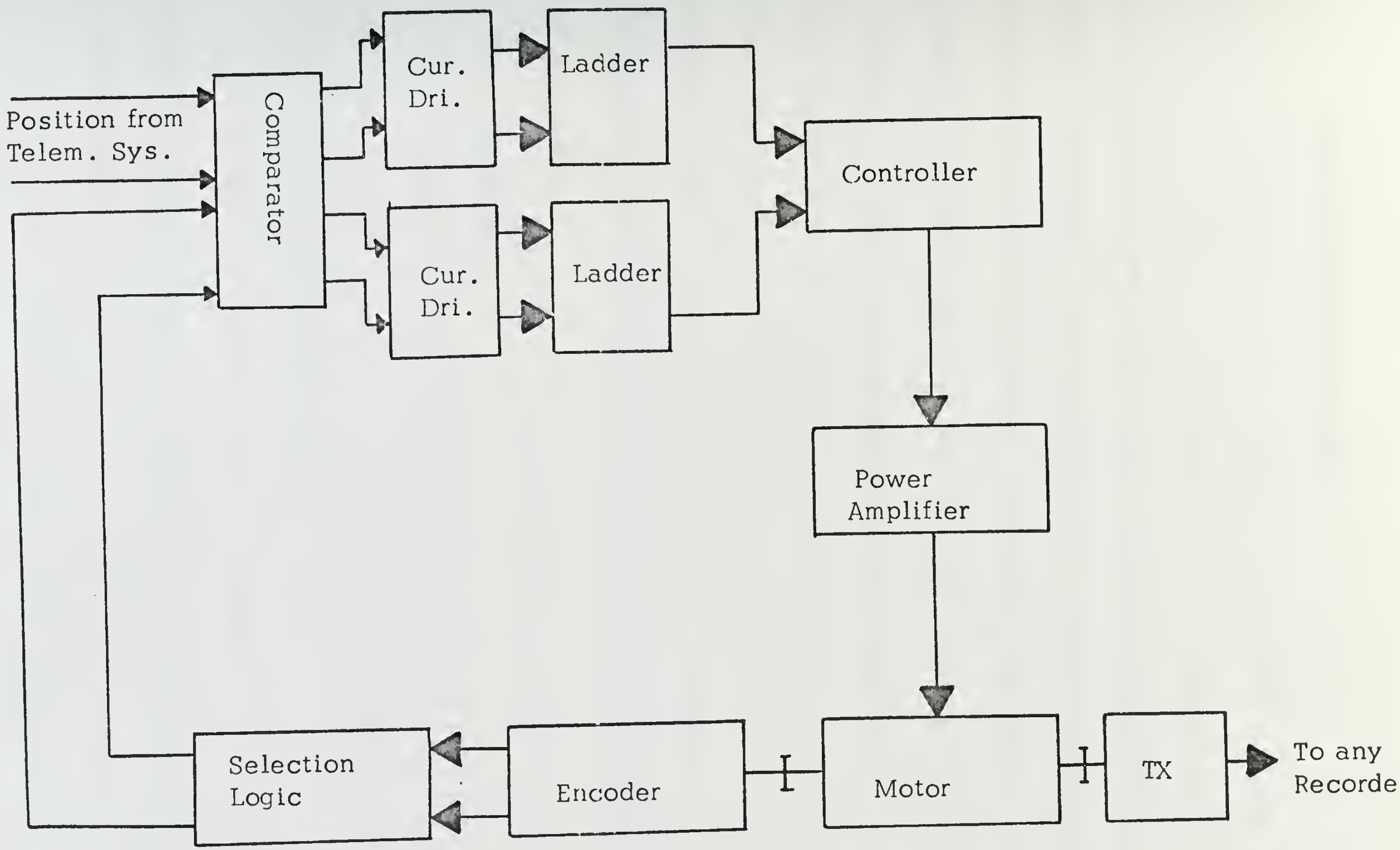


Figure 39. Digital servo system
(Cur. div.: current driver)

2. Digital to Analog Converter

For digital to analog conversion, two ladder networks are used for C and D outputs of bit comparators. This circuit is given in Fig. 40. In this ladder the open-circuit output voltage is one-half the voltage at input 1 to resistor R_2, plus one-fourth the voltage at input two plus one-eight of the voltage at input three. Thus the resulting open-circuit output voltage is a properly weighted sum of the individual bits. If R_1 is 1KΩ and R_2 is 2KΩ, input resistance to each section of the ladder becomes 2KΩ, and each output of the level amplifier (in this case μL900 medium power buffer) has a load resistance of 3KΩ. Two D/A converters, as described above, will give two voltage levels; the difference between the two voltages is proportional to the error angle and the direction of error can be sensed.

3. Controller

The controller is a basic analog comparator with a voltage follower, and is used to generate a positive voltage level to the control power amplifier for driving the motor.

For this application a μA710 comparator is used. The input currents of this amplifier are high enough to cause significant error due to the loading of the ladder network. However, a transistor pair can be used in front of the comparator to reduce these input currents. The only disadvantage of this configuration is that the speed of the comparator will be affected somewhat by the addition of the input stage. This is caused primarily by collector base capacitance of the input transistors

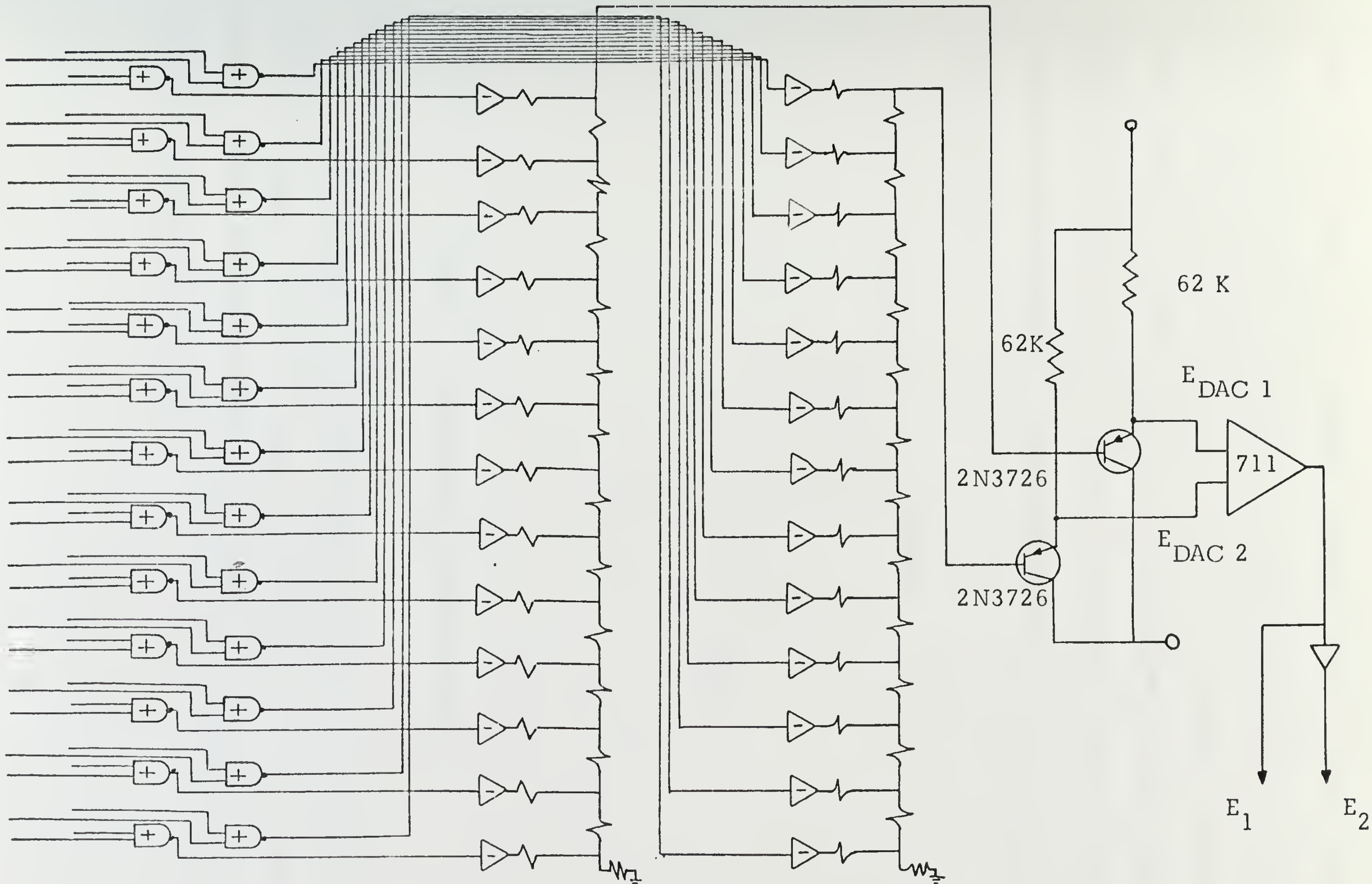


Figure 40. Comparator, D-A-converter, controller

loading the source. The transistors shown in this circuit are selected for low collector base capacitance and high current gain, [Ref. 16]

The input voltage range is ±5.0V. Two voltages are supplied from the digital to analog converters and vary between 0 and +3.0V. The output of the circuit will be -0.5 and +3.2 V levels, which are enough to control the power amplifier. The transfer function for the comparator is is given in Fig. 41.

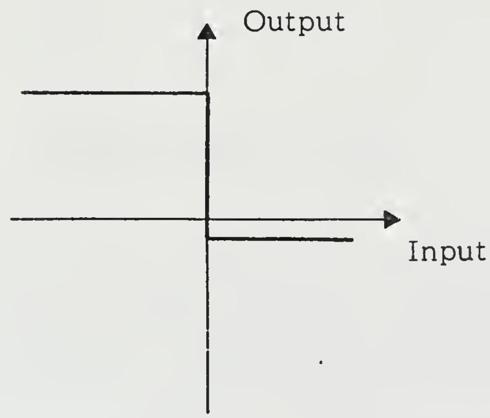
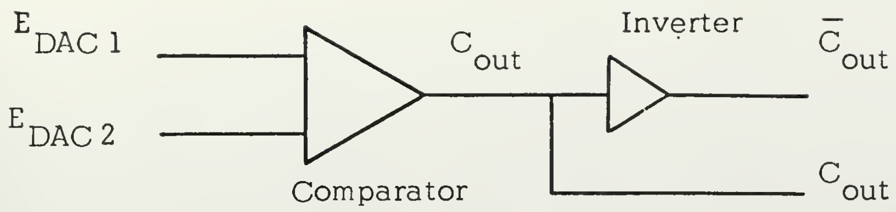


Figure 41. Comparator transfer function

When E_{DAC2} is higher than E_{DAC1}, output will be high, and whenever E_{DAC2} is less than E_{DAC1}, output will be in the low state. output and its complement will be used to drive the power amplifier for direction of the motor, Fig. 42.



	C_{out}	$\bar{C}_{out}$	E_1	E_2	Direction
$E_{DAC\,1} > E_{DAC\,2}$	H	L	1	0	CW
$E_{DAC\,1} < E_{DAC\,2}$	L	H	0	1	CCW

Figure 42. Direction control of motor

4. Power Amplifier

This power amplifier is modified from a bidirectional switching power amplifier given in Ref. 16. The output of the controller and its complement is fed to this circuit as E_1 and E_2 for direction control.

When E_1 is high and E_2 is zero, this will turn on Q_3, and the supply voltage will be divided between R_3 and R_5. This voltage will feed Q_5 and it will be turned on.

The full supply voltage generates a current to ground on the path V, 1, 2, 3, 4, ground, giving R_L a positive direction. Alternatively, when E_2 is high and E_1 low, the same explanation applied as for Q_4, Q_2 and Q_6. The current will follow the path V, 6, 5, 4, 3; this will cause a negative current direction in the load. For a high state, a voltage between $0 < V < 5$ is enough. The output of the comparator and its complement can be used to drive the power amplifier, Fig. 43.

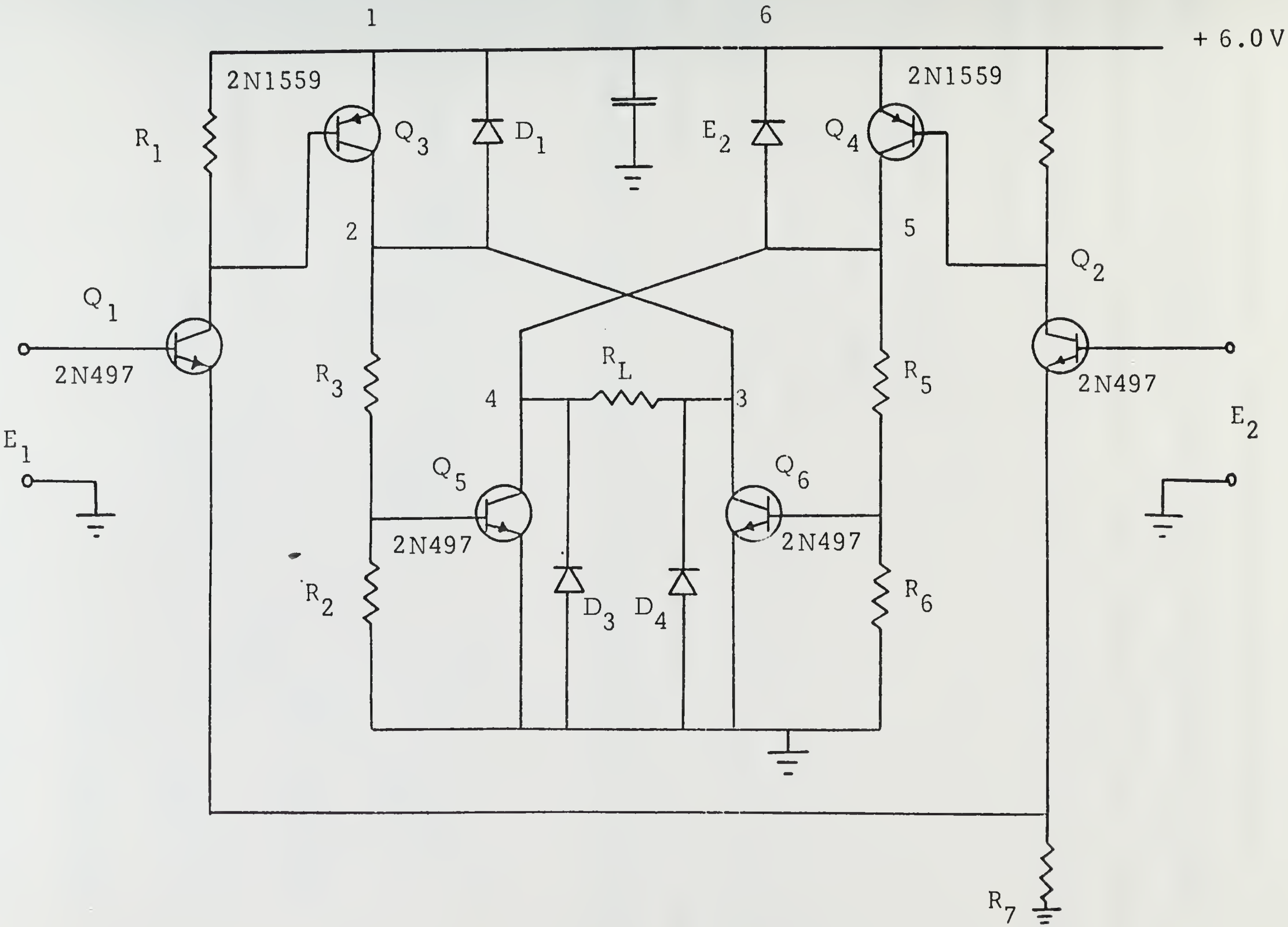


Figure 43. Power Amplifier

VII. FIELD INTENSITY RECEIVER WITH VOLTAGE CONTROLLED ATTENUATOR

A. GENERAL DESCRIPTION

A basic configuration of this equipment is given in Chapter II. In this chapter, the principle of a field intensity receiver with a voltage controlled attenuator is presented. Possible usage of several logarithmic attenuation elements and circuit configurations, and a design for HF and UHF range are given.

B. PRINCIPLES OF OPERATION

1. Field Intensity Meters

The field intensity meters are similar to the communication receivers, Fig. 44. The differences between the conventional receivers and the field intensity meters arise because of the basic requirement that the field intensity meter be capable of accurate quantitative measurements.

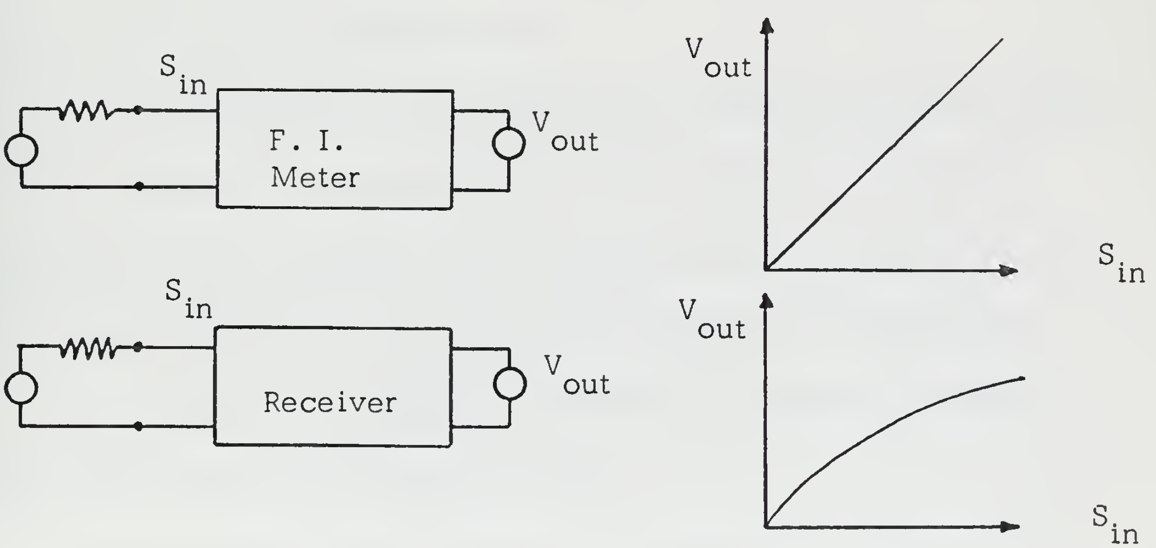


Figure 44. Gain comparison of the F.I. meter and the regular receiver

The reason for similarity is that the amplification and detection of the field senses by the antenna is necessary in both cases. In the case of the field intensity meter the output is a calibrated indication of the voltage generated at the antenna terminals; in addition to this, the level of proportionality is adjusted by adjusting the gain of the field intensity meter by means of external or internal calibration source. This is achieved by a field intensity meter which has the functional diagram shown in Fig. 45.

2. Receivers with Voltage Controlled Attenuators

The communication receivers are not required to generate an accurate quantitative measurement of the voltage at the input terminal. The requirement of the receiver in this sense is therefore much simpler. In the case of a communication receiver the output is a nonlinear uncalibrated function of the signal amplitude at the receiver input. Therefore, the gain of a particular receiver is constant only when the signal amplitude at the input terminals is constant. The measurement of field intensity can be achieved by the following steps:

a. The adjustment of the receiver to a predetermined input level.

b. Maintaining the input level to the receiver at a constant level as the voltage appearing at the antenna terminals increases by inserting attenuation between the antenna and receiver input terminals.

c. Recording the change in attenuation as changes in field strength observed by the recording antenna.

The adjustment of any receiver to a predetermined input level is achieved by using a calibration source. Different receivers will give

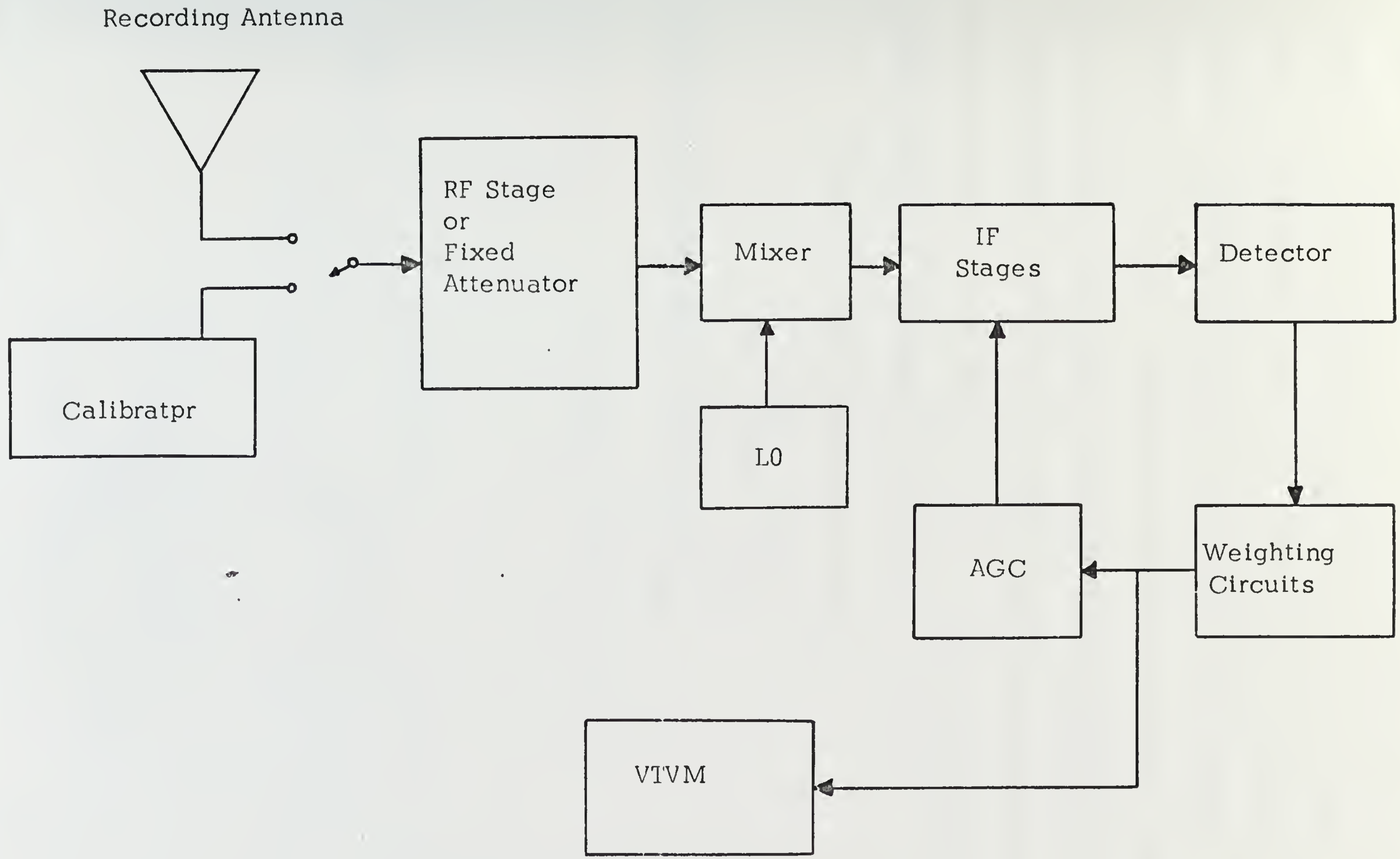


Figure 45. A field intensity meter

different output voltages with the same calibration signal at the input terminals. This is adjusted by subtracting the output voltage at calibration from the output during test. Therefore, a zero level at the output indicates the predetermined level at the input of the receiver. Since many different receivers are employed this subtracted reference value must be an adjustable voltage source. The presence of a voltage after subtraction is an indication that the receiver input voltage has changed from the predetermined level. This voltage is used to change the attenuation in order to return the input level to the set value. Fig. 46.

These are simply formulated as follows:

$$V'_c = V_{OUT} - F(S_{CAL}) \tag{34}$$

At the predetermined level. Thus $S_{IN} = S_{CAL}$

$$V'_c = F(S_{CAL}) - F(S_{CAL}) = 0 \tag{35}$$

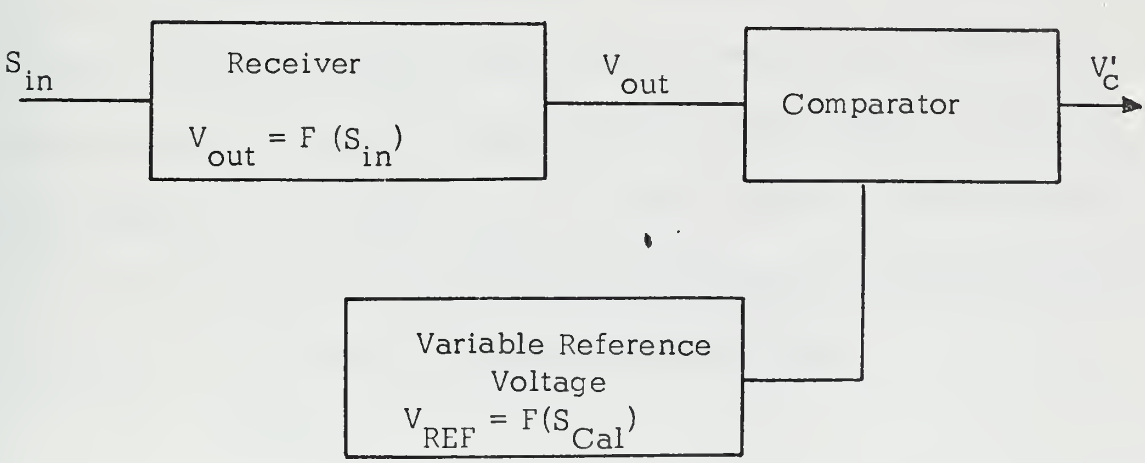


Figure 46. Adjustment of the output of the receiver

For any receiver, since

$$V_c = hV'_c$$

and

$$S_{IN} = a(V_c) \cdot S,$$

the relation between the signal amplitude and the control voltage is

$$S = \frac{S_{IN}}{a(V_c)}, \tag{36}$$

where $a(V_c)$ is the attenuation function; and if attenuation is an exponential function of the control voltage,

$$a(V_c) = a_o \cdot \text{EXP}\,[-b \cdot V_c] \tag{37}$$

where h and b are factors to be identified later and

$$a_o = \text{insertion loss}$$

3. Voltage Controlled Elements

Voltage controlled attenuation is generally employed in circuits such as amplitude modulators and linear compensation. For a field intensity meter, voltage controlled attenuation has been employed by using piston-type attenuators driven mechanically by servo motors. The frequency range of this equipment was 1.5 MHz - 18 MHz. Today the state of the art of semiconductor devices has introduced new elements for this application. Some of them are explained briefly below.

a. Varactors

Varactors are voltage controlled capacitors and can be used as voltage dividers at high frequencies.

These are diodes whose junction capacitance varies with applied voltage. An equivalent circuit for this type element is given in Fig. 47.

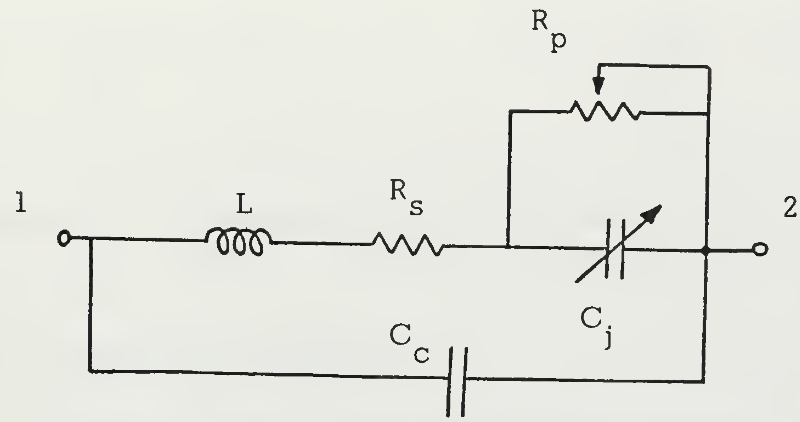


Figure 47. Equivalent circuit for varactor

In this figure, L is the series inductance due to leads and attachments. R_s is the ohmic resistance plus leads resistance. C_c is stray capacitance of the diode. C_j is the internal capacitance which is variable with V_{12}, and R_p is the internal leakage resistance.

b. PIN Diodes

The current controlled microwave resistor is a PIN diode whose series resistance is controlled by changing the current between terminals. PIN diodes are fabricated by diffusing P type impurities into one side of a wafer that has an expitaxially-grown, high-resistivity layer. This intrinsic layer provides variable resistance in the microwave range. At low frequency this device exhibits rectification properties, as does a PN junction. However, charge storage in the intrinsic region prohibits rectification at frequencies between 10 MHz - 10 GHz.

An equivalent circuit of a PIN diode is given in Fig. 48.

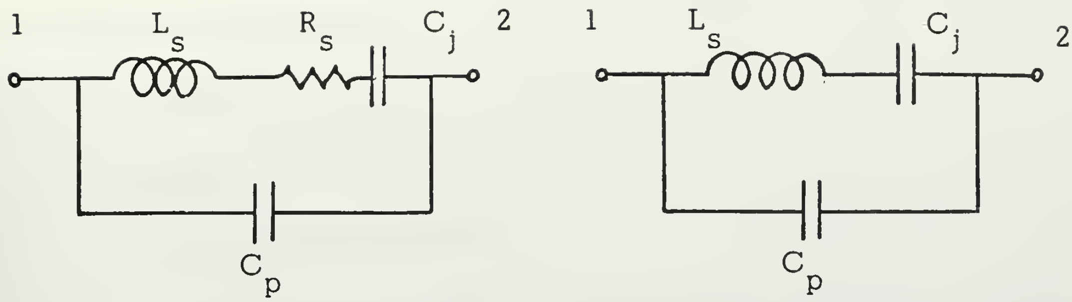


Figure 48. Equicalent circuit for PIN diode

c. Field Effect Transistors

These are other types of variable resistors. The drain current voltage characteristics of field effect transistors remain linear for low drain to source voltages. This is the region where pinching off the conducting channel is avoided. Variable resistance in a linear fashion is then obtained in a 1:4 range. Using higher potentials between gate and source, a higher range is obtained by using several types of field effect transistors. The relation between variable resistance and control voltage is satisfied. The following equation states this empirically:

$$R = R_o \exp [b \cdot V_c] \tag{38}$$

These types of elements can easily be used as voltage controlled attenuators. b can be varied by different techniques.

C. DESIGN OF A FIELD INTENSITY RECEIVER

After the general characteristics of the voltage controlled attenuator are obtained, the complete system for a field intensity receiver can be designed. This design is given below, component by component,

in the following paragraphs under the considerations of the functional diagram in Chapter II, Fig. 3.

1. Receiver

a. Input Characteristics

The input impedance of the receiver is 50 ohms nominally. In a regular receiver this value changes depending on frequency. Therefore the input of the receiver must be isolated.

b. Output Characteristics

The audio output will be used for this purpose; the audio output of navy receivers is matched to 600 ohms and at this value of load impedance the output changes between 0 - 4 volts RMS.

c. Gain

The gain of the receiver must be high and can be obtained by cancelling AGC. The receiver must be capable of amplifying its input to a usable level with the minimum expected antenna voltage decreased by the insertion loss of the attenuator.

2. Comparator

The comparator can be designed in two sections; a peak-to-peak detector and a comparator using integrated circuits.

a. Peak-to-Peak Detector

The circuit shown in Fig. 49 is constructed and used to get a better response than can be obtained from diode rectifiers. This is especially important in low levels to reduce threshold effects.

With the variation of input voltage from 0 - 3 V Rms, linear

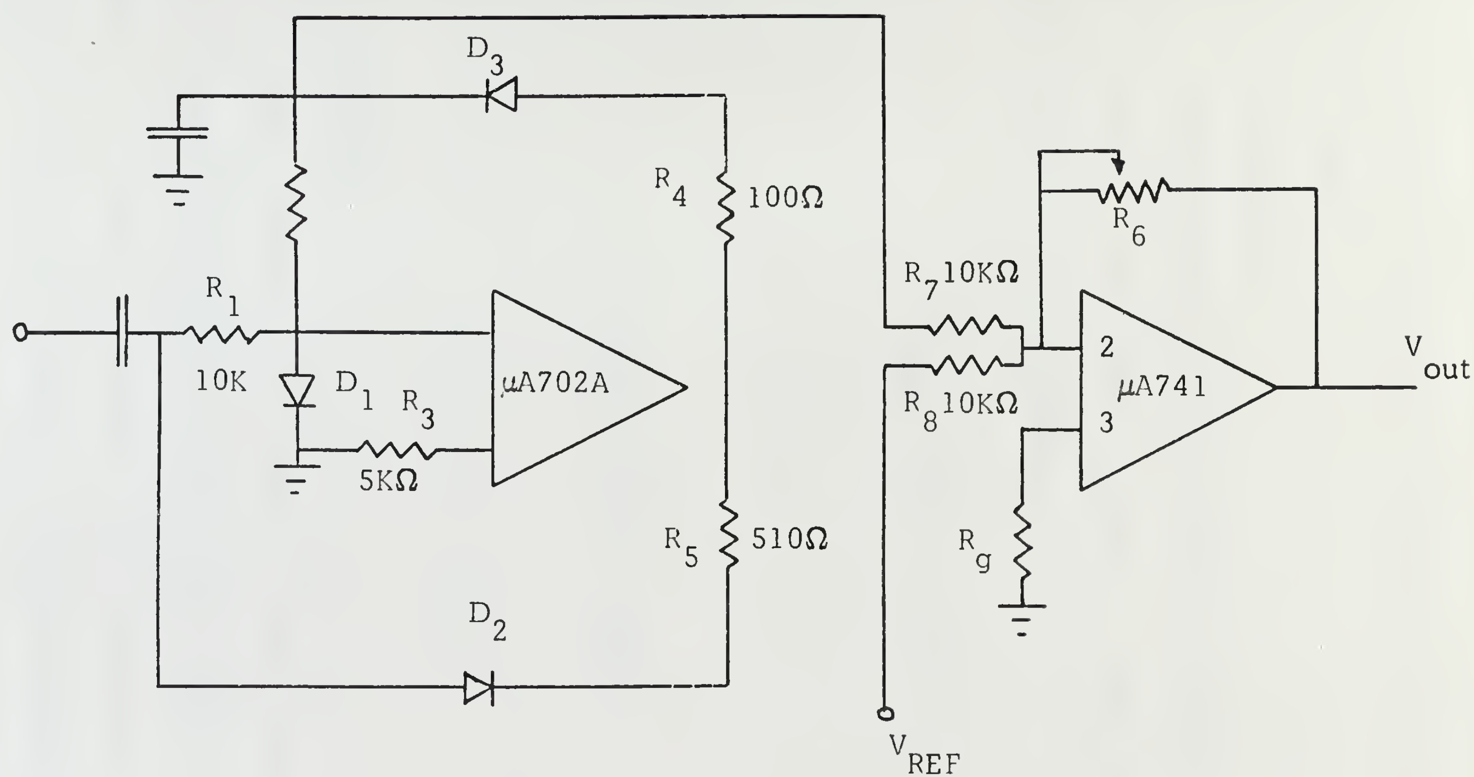


Figure 49. The Comparator Circuit

variation of output from 4.2V to 6.6V is obtained. This linear voltage can be used as an indication of the output level of the receiver. At zero output of the receiver, the output of the detector can be compensated by the reference voltage.

b. Comparator

With another (μA741) operational amplifier, the reference voltage is subtracted from voltage V_1; then the slope of the voltage can be adjusted. This is given as follows:

$$V_{OUT} = \frac{-R_6}{R_7} V_1 + \frac{R_6}{R_8} V_{REF}$$

where $R_7 = R_8$.

Then
$$V_{OUT} = \frac{R_6}{R_7} (V_1 - V_{REF})$$

or
$$V_{OUT} = k\,(V_1 - V_{REF}) \tag{33}$$

3. Controller

To obtain proper control voltages for two voltage controlled resistors, operational amplifiers will be used. Addition and subtraction of voltages are used for this purpose. The input voltage to this circuit is the output voltage of the comparator, which is proportional to the input signal S_{in}. The comparator output V_c is multiplied by a factor $h = \frac{R_{12}}{R_{10}}$ to obtain the attenuation voltage for the series arm V_{cl}. This

voltage will increase with increasing V'_c and its range will be from 0 to $V_{c\,max}$. The parallel arm must have its highest resistance for lowest attenuation and lowest resistance for highest attenuation. This can be achieved by decreasing V_{c2} from $V_{c\,max}$ to zero, which is accomplished as V'_c increases by subtracting V_{cl} from $V_{c\,max}$, Fig. 51.

These two voltages are then applied to the voltage controlled attenuator which is shown in Fig. 53.

4. Voltage Controlled Attenuator

The basic principle of the attenuator is shown below. It is a basic voltage divider which is followed by a high inpur resistance stage; this has a gain of one. The sole reason for the use of this amplifier is to obtain high input resistance so as to have proper voltage division in the voltage divider.

The variable resistance elements shown in Fig. 50 will be field effect transistors. For controlling the resistances, the bias circuit in Fig. 52 will be used.

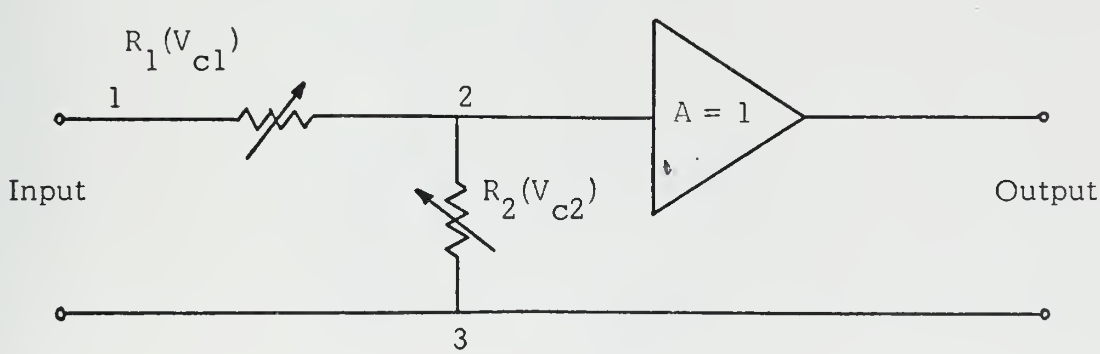


Figure 50. Basic configuration of the voltage controlled attenuator

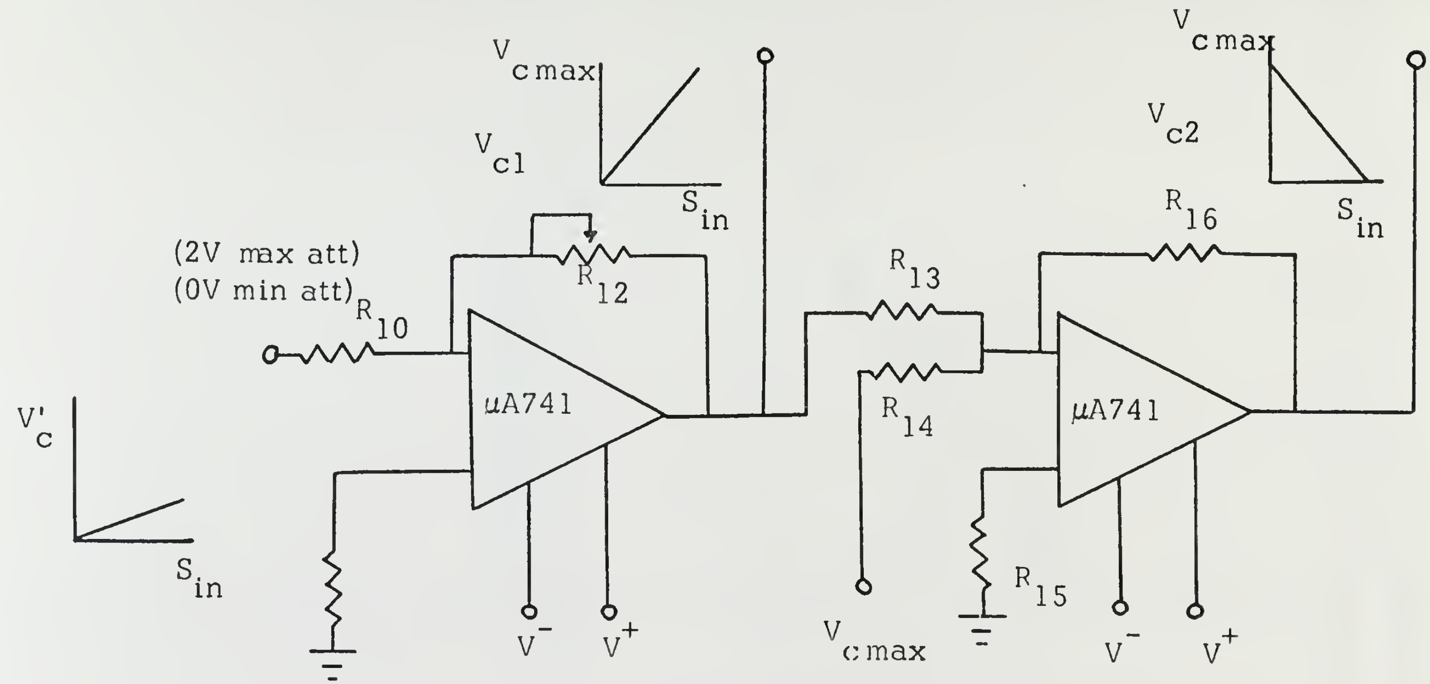


Figure 51. Controller

R_{DS} is found to be logarithmic with the changing voltage V_{GS}. V_{GS} can be controlled with V_{c1} or V_{c2} to get the required R_{DS} which is R_1 or R_2. The range obtained for R_{DS} is 0.2k - 800 k ohms, and the logarithmic is 0.4 k Ω - 200 kΩ with control voltage limits of 4.0 to 10.0V. This gives a ratio of 500. An attenuator can then be designed for a range of 54 db with constant input resistance. This circuit is shown in Fig. 53.

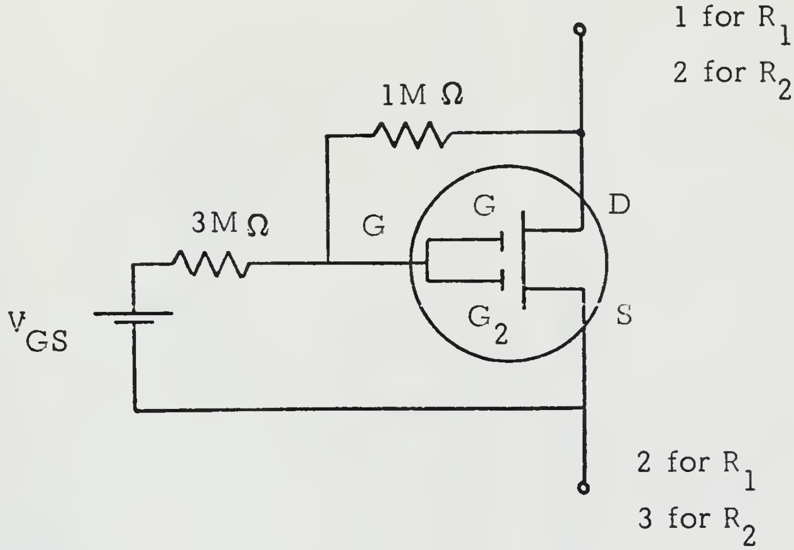


Figure 52. Bias circuit for field effect transistor as a voltage controlled resistance

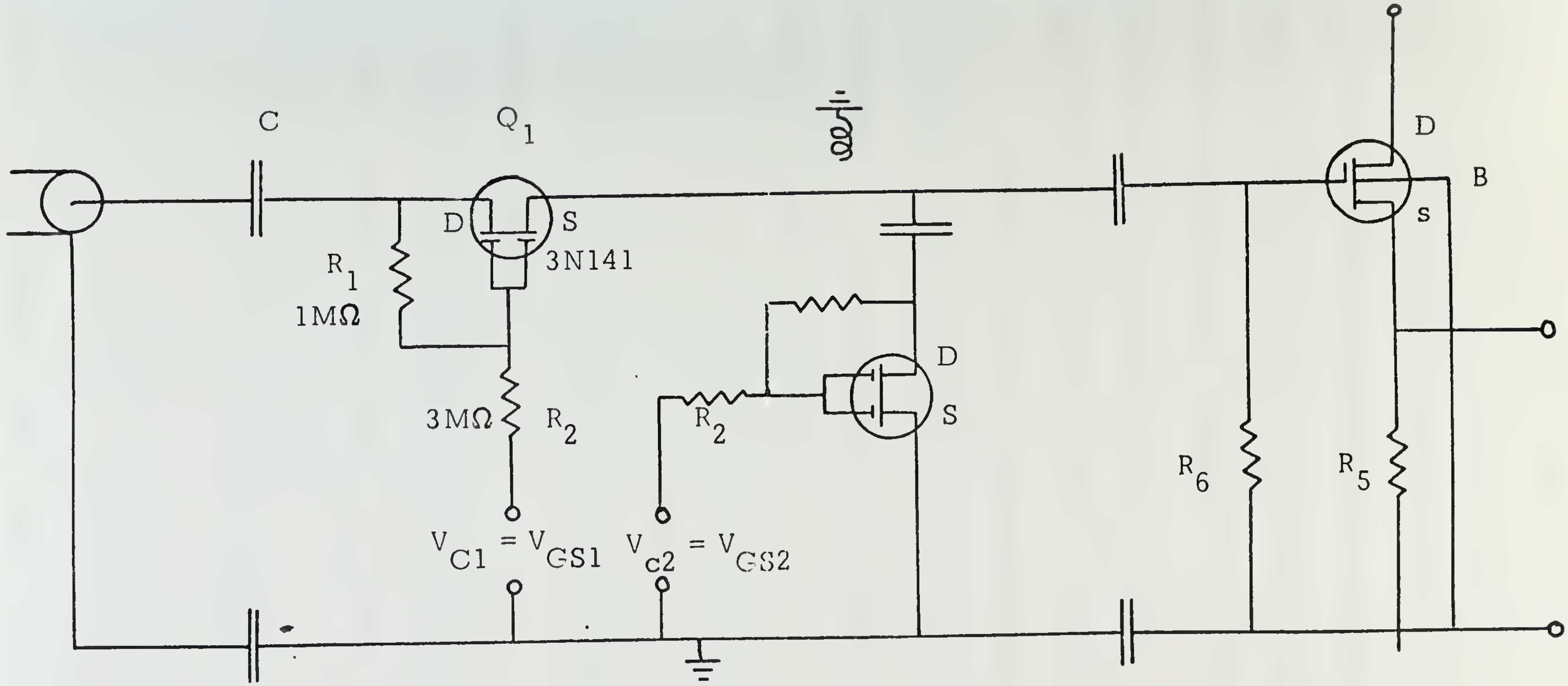


Figure 53. Voltage controlled attenuator

VIII. CONCLUSIONS

The feasibility of a design for a range to be used for measurements of the radiation in naval vessels has been studied. An antenna range has been proposed for implementation in three phases. The practicality of the methods chosen permits small size navies to have the opportunity of improving the efficiency and performance of shipboard radiating systems. The actual cost is not calculated, but has been kept low by specifying discrete equipment instead of complete packages.

It is understood that the characteristics of an antenna range for the measurement of the performance of antennas onboard a vessel will vary considerably from those of an off-site antenna range. This affected the selection of methods significantly.

This paper includes general outlines for the design and development of an antenna range and the detailed design of necessary special equipment in order to achieve the measurements which will meet the most immediate requirements.

Further studies could be done for the designs necessary in phases two and three, especially studies on underwater detection system measurements and ECM measurements.

It is suggested that the impact of range measurements on the combat efficiency of a ship would be enhanced if ship commanders and higher authority were provided with, in each case, an operations research evaluation based upon the range measurements obtained on the antenna patterns, systems performance and personnel effectiveness.

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13. ABSTRACT

The need for a range to measure the effectiveness of ships' radiating systems is described. A three-step long-range plan is presented for the establishment of such a range. Special consideration is given to minimum cost, particularly in the initial phase. A design is given for this phase in which the key units are presented in detail. Readily available commercial or standard navy units are specified wherever possible. Options are presented and suggestions for future extension of range capability are included.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Shipboard antennas						
Measurements						
Radiation patterns						

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